European Radiocommunications Committee (ERC)
within the European Conference of Postal and Telecommunications Administrations (CEPT)

# THE ANALYSIS OF THE COEXISTENCE OF TWO FWA CELLS IN THE 24.5 - 26.5 GHZ AND 27.5 - 29.5 GHZ BANDS

**Edinburgh, October 2000**

## EXECUTIVE SUMMARY AND CONCLUSIONS

The SE19 target is to provide guidelines for the deployment of 26/28 GHz FWA systems initially addressing the most common systems.

The applicability limits of the current version of the report are as follows:

- TDMA and FDMA access methods as described in the ETSI EN 301 213-1,-2,-3 standard
- 3.5, 7, 14 and 28 MHz channel sizes with 4 level modulation schemes

56 and 112 MHz systems with any modulation schemes are not analysed because of lack of suitable parametric data. Systems with high order modulation schemes are for further study. It is worth noting that 3.5, 7 and 14 MHz systems with any modulation schemes are expected to be compatible with the current conclusions if the interfering system has channels narrower than 28 MHz.

It is intended to update the report in order to cover CDMA, Multi-Carrier TDMA and other technologies.

The report considers two operator deployment scenarios:

1. Systems operating in the same or partly overlapping area
   and
2. Systems operating in adjacent or nearby areas

A number of different methods have been used to assess the severity of interference. These are:

- Interference Area (IA)
- Interference Scenario Occurrence Probability (ISOP)
- Monte Carlo (MC)
- Worst Case (WC)

Using the above methods it has been possible to estimate the probability of interference between FWA systems. From these results, estimates have been made of the frequency and/or geographical spacings needed between these systems in order to reduce the level of interference to an acceptably low level. Since many system parameters are not defined by available standards and because the effects of buildings and terrain are very difficult to model, absolute recommendations cannot be given. The report therefore gives guidelines that will lead to acceptably low levels of interference in most cases.

In several cases unacceptable interference occurs when the Terminal Stations (TS) are placed only in certain areas of a cell or sector. The **Interference Area (IA)** is the size of this area relative to the total cell or sector area.

The **Interference Scenario Occurrence Probability (ISOP)** is defined as the probability that an operator places at least one terminal in the IA. ISOP is related to the number of terminals deployed by the operator, and possibly to the cell planning methodology. The ISOP method evaluates the guard band required in order to meet an interference probability lower than a certain value.

The **Monte Carlo (MC)** method is used to evaluate interference probabilities for the case of interference between terminals (TDD-FDD, or TDD-TDD systems). This case is not readily amenable to analysis. Terminals are placed at random in the interacting cells or sectors, and the interference between each possible pair of terminals evaluated. Statistics are computed based on the number of interacting pairs and the total number of terminals.

The above methods are relevant to the low interference probability that is expected in scenarios where the interference depends on the random locations of the terminals on customer premises, e.g. the TS to CS interference scenario.

The **Worst Case (WC)** method derives system deployment parameters to ensure that interference is always below a set threshold for all cases.

The analysis, carried out with all the methods above, is based upon pessimistic assumptions relevant to the system deployment, except for certain system parameters. These parameters are based on measured results for one typical system and are used because of the lack of a complete and meaningful set of such parameters within the ETSI EN 301 213-1,-2,-3 standard. However some analysis is given about the sensitivity of the results to variation of the set of parameters.

| Operators deployment scenario | methods | Guard band/distance estimations | | Notes |
|---|---|---|---|---|
| | | FDD | TDD* | |
| **Same area – adjacent frequency blocks **** | Hub ****to Terminal (based on ISOP and IA) | 1x28MHz | 1x28MHz | XPD usage can allow provision of more flexible guard bands Notes 1, 2, 8 |
| | Terminal to Terminal (based on ISOP and MC) | _ | 1x28MHz | Notes 1, 2, 5, 8 |
| | Hub to Hub (based on WC) | _ | 2x28MHz | As alternative TDD can perform 1x28 MHz guard + a hub-hub coordination distance. XPD usage can allow provision of more flexible guard bands Notes 1, 4, 8 |
| | Operators co-operation | None or reduced to a minimum according to a case by case evaluation | | Notes 1, 6, 8 |
| **Same frequency block – adjacent area ***** | Hub to Terminal (based on WC) | >20km | >20km | Notes 3, 7, 8 |
| | Terminal to Terminal (based on MC) | _ | >20km | Notes 3, 5, 8 |
| | Hub to Hub (based on WC) | _ | >40km | Notes 3, 8 |

**Guard band/distance estimations for typical system parameters**

* for both TDD and mixed TDD/FDD system deployments
** a full interference LOS is assumed
*** note that guard distances are expressed as distances between the area boundaries
**** Hub = Central Station

NOTE 1: The table above reports the guard band requirements in terms of 28 MHz slots as 28 MHz is the greatest channelisation considered in this report and a 28 MHz guard band will in most circumstances provide a reasonably interference free scenario both with other 28 MHz systems and with lower capacity systems. Hence it is considered an acceptably safe solution. When the planning criterion is based on the “case by case evaluation” the actual guard band can be stated in accordance with the result expressed in section 4.2.1.4. It is to be noted that lower capacity systems would require an increased guard band in terms of the number of the narrower channels.

NOTE 2: The ISOP has been evaluated according to the assumption of 15 terminals per sector per operator; 4 available channels per operator; and a frequency reuse factor of one. The ISOP figure varies approximately linearly with the assumed number of terminals, with the assumed number of channels and with the assumed frequency reuse factor. Both the IA and ISOP depend on the relative EIRP of the victim and of the interfering. A 6 dB relative increase of the interfering power increases the IA and ISOP figures by an approx. factor 1.4. A 6 dB decrease of the interfering power decreases the IA and ISOP figures by an approx. factor 4.4.

NOTE 3: The table above reports the guard distance requirement for 3.5 MHz channel width systems. This guard distance will in most circumstances provide reasonably interference-free operation with systems of similar or higher capacity. It is therefore considered an acceptably safe solution. When the planning criterion is based on a “case by case evaluation” the actual guard distances can be decreased as stated in accordance with the result expressed in section 5.

NOTE 4: The hub to hub interference scenario is the most dangerous since it can create a complete sector blocking to both neighbouring operators. The ISOP or IA methods and the possible countermeasures (described in section 2.1) can be considered irrelevant when applied to this scenario. A 2x28 MHz guard band will allow un-coordinated deployment of TDD and FDD systems of any channel bandwidth up to 28 MHz. However even with 28 MHz guard band the minimum spacing between a TDD site and any other site may be 500 m or less, depending on system bandwidth. Minimum spacings down to below 50 m are possible for some system combinations. When the planning criterion is based on the "case by case evaluation" the actual co-ordination distance can be stated in accordance with the result expressed in section 4.3.1.

NOTE 5: ATPC (Automatic Transmitter Power Control) capability has been assumed for the uplink direction only, it is not considered in the downlink direction.

NOTE 6: Co-siting or near co-siting co-operative deployment (here intended just as the hub tower sharing with no other systems co-ordination involvement) is a valid option for symmetric FDD systems only, since it is based on the assumption of a coordinated up/down band arrangement. This assumption can not be applied to asymmetric FDD or TDD systems, which would require careful site engineering by both operators and always requires close cooperation.

NOTE 7: Two scenarios are analysed by the report:

- The result of the downlink (hub to terminal) scenario is a guard distance estimation of about 20 km.
- The result of the uplink (terminal to hub) scenario is a guard distance estimation of about 55 km. The different result in respect to the above downlink scenario is due to the possibility of no rain attenuation correlation. This guard distance can be reasonably reduced to 40 km, taking into consideration the obstruction effect inside the 1st Fresnel ellipsoid due to the earth curvature at typical antenna tower heights (e.g.30 m).

It is worth noting that the occurrence probability of the rain uncorrelation interference scenario in the uplink case is quite low ( according to the ISOP method). Therefore the alternative adoption of 20 km as a reasonable minimum guard distance can be suggested.
See further explanation in section 5.3.

NOTE 8: The guard band and distance estimations for other systems architectures such as MP-MP systems may differ from those in the table. These are for further study.

# INDEX TABLE

# THE ANALYSIS OF THE COEXISTENCE OF TWO FWA CELLS IN THE 24.5 - 26.5 GHz AND 27.5 - 29.5 GHz BANDS

## 1 INTRODUCTION

The scope of this report is to investigate the coexistence of Point to Multi-point systems, developed in accordance with the ETSI EN 301 213-1,–2,-3 and with the CEPT channel plan, defined by the ERC Recommendation T/R 13-02.

Interference problems may occur when systems, owned by different operators, operate in:
a) adjacent frequency blocks in the same area or,
b) in the same frequency block in adjacent areas.

This report aims to assist the administrations in the assignment of frequency blocks to the operators who operate FWA systems in the bands 24.5 - 26.5 GHz and 27.5 - 29.5 GHz.

### 1.1 The frequency licensing policy and the possible approaches, the ISOP scenario

When considering the adjacent frequency blocks, same area scenario, the possible process of the frequency licensing is shown in Figure 1, where two approaches are defined. In the first approach, called “planned deployment”, the administration aimed to provide, to both operators and end users, a reasonably interference free environment, by limiting the Interference Scenario Occurrence Probability (ISOP) or Interference Area (IA) to a low level, by stating the guard band required between the assigned spectrum blocks.

An administration could set a probability criterion, for the ISOP or IA, which is deemed to be acceptable and derive the corresponding guard bands (by estimation based on the methods explained on following sections). In this case the guard bands are explicitly outside the spectrum block assigned to the operator.

The second approach, called ”unplanned deployment”, implies that the entire burden is put on the operators. In this case the guard band is included in the blocks assigned to the operators, provided that the blocks are consequentially larger. In this case the “interference free environment” is not ensured by the administration but by the operators themselves. It is up to them to possibly co-ordinate with operators using adjacent blocks. Several possibilities exist in order to facilitate coexistence without reducing the spectrum efficiency by the introduction of excessive guard bands, but all of them imply a certain co-operation between operators using adjacent blocks. Such possibilities include arrangements for site sharing (or near site sharing), agreements for the use of different polarisation in each sector, or for co-ordinated cell planning.

In the case of unplanned deployment operators have to co-operate; if they don’t they waste the spectrum. However the co-operation might not be practical in all situations.

A possible compromise is when the planned deployment foresees a second step in which there is a convergence towards the unplanned deployment. In this second step the neighbouring operators, which agree the co-operation, could jointly consult the administration and finally could get the assignment of the guard bands.

From the above discussion we can derive that the guard band (introduced explicitly outside the blocks in the case of planned or inside them in the case of unplanned configuration) can be interpreted as an ”edge” band. This means that, in the case the operators co-operate, the guard band can be reduced or even eliminated thanks to mutual agreements on how to access spectrum over the same area.

The following flow-chart shows the different approaches that one administration might use in order to assign the spectrum to different operators.

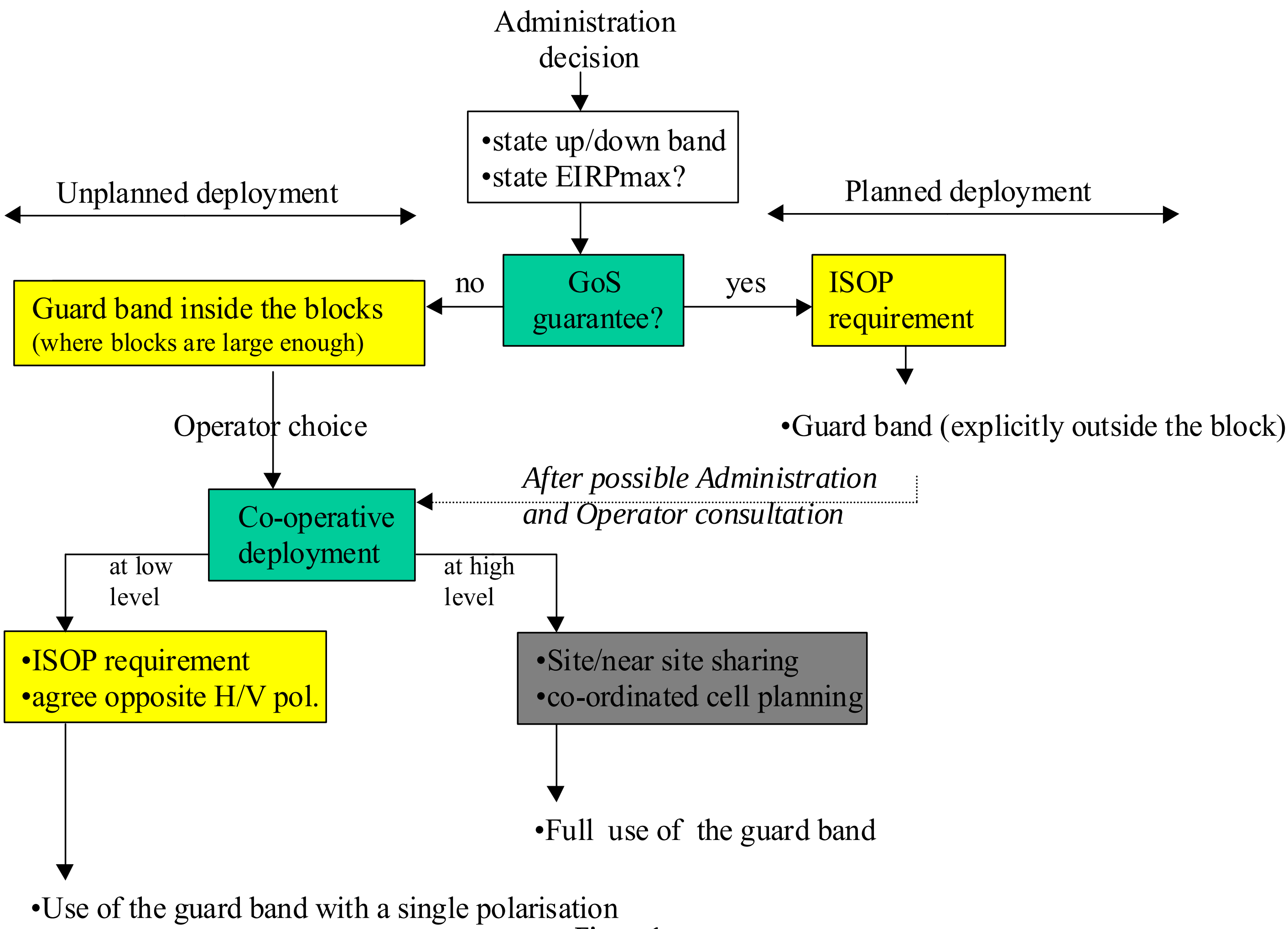



**Figure 1**

### 1.2 The Worst Case deployment scenario

The most efficient way of evaluating the guard bands should be through a "case by case" evaluation.
This would imply that the administrations should, in the application phase, analyse the actual behaviour, the planned coverage range, the hubs location, the cellular structure and the cell planning aspects of the system operated by the operators in any particular area.

The administrations should therefore analyse all the possible interference combinations that the PMP ETSI standard (EN 301 213-1,-2,-3) makes possible: different access schemes, modulation schemes, duplex schemes and capacity from 4 to several hundred Mbit/s. Beside that, they need to consider that operators could have different deployment requirements. They could have different BER threshold and availability requirements (typically, from 99.9 to 99.999%, sometime including and sometime excluding hardware reliability into their availability evaluation) and they could deploy systems with different system gains (up to several dBs). This strongly impacts the coverage range, the cell planning and the frequency reuse allowed by the systems operated by different operators and dramatically increases the number of interference scenario combinations.

Hence the "case by case" evaluation is not likely to be a viable, or at least the most preferred, solution, due to the following reasons:

- The number of possible different deployment scenarios is so huge that it is unrealistic to think that administrations could look after all of them
- Operators could change their system or deployment after a period of time without warning the administration and the previous guard band evaluation could become wrong
- Due to the inflexible nature of the T/R13-02, such a big effort doesn't always guarantee a relevant guard band saving

For the above reasons, a more realistic approach is by deriving the guard band requirements, according to an ISOP evaluation and according to a worst case deployment scenario.

In a second step, as described in the flow chart in section 2.1, operators are encouraged to co-operate. After further consultation with the administration, they could, fully or partially, use the guard (or, better say, edge) bands.

## 2 DESCRIPTION OF THE ASSUMPTIONS ON SYSTEM PARAMETERS AND DEPLOYMENTS

As mentioned in section 2.2, the number of interference scenario combinations is huge and the only way of providing meaningful results is through the definition of a simplified model for the analysis of the interference occurrence. The model here proposed is based on some assumptions and approximations, here below explained.

- The assumed system parameters are based on measured results for one typical system and are used because of the lack of a complete and meaningful set of such parameters within the ETSI EN 301 213-1,-2,-3 standard. The same (equalised) parameters are used for both the victim and the interfering systems. This assumption, that could be optimistic in several cases, is strongly compensated by the very pessimistic assumptions on system deployments and interference levels.

- System deployments are based on the worst case assumptions. These assumptions, which are really pessimistic in several cases, are here below described:
  - ✓ Each sector is assumed to be victim of an interfering hub or CS (Central Station). It is worth noting that this assumption is realistic only when the victim sector size is double than the interfering one. It is worth noting that assuming instead similar sector sizes, only one sector out of four (considering 90°-sector deployments) could suffer interference problems.
  - ✓ The sector frequency reuse factor, used for the cell planning deployment, is assumed equal to 1. It is worth noting that most systems perform instead a frequency reuse factor which is equal or bigger than 2.
  - ✓ No rain correlation between the victim and interfering signals is assumed. The assumed sector and rain cell sizes are the ones relevant to the ITU rain zone K (42mm/h) and to systems satisfying an availability requirement equal to 99.99%. It is worth noting that lower rainfall rate (e.g. ITU zone E) would provide a lower interference probability as the ratio between the rain cell size and the sector size is bigger. It is also worth noting that an higher rainfall rate (e.g. ITU zone L) would provide lower interference amount as the rain cell size is bigger than the sector size and the rain uncorrelation scenario becomes impossible. See annex 2 for the evaluation of the coverage range and the cell rain size in different rain zones. In any case, the acceptable level of interference is assumed to be obtained for the percentage of time corresponding to rain failure limit.

- The guard band and distance evaluation is based on the worst case assumptions, which are here below described:
  - The interference level is calculating according to the boresight antenna gain
  - The interference level is calculating according to a full LOS assumption
  - The guard band, suggested in the conclusions, is the one related to the largest channel size system
  - The guard distance, suggested in the conclusions, is the one related to the smallest channel size system

Other assumptions used, as reference for the interference probability evaluations, are as follows:

- The number of physical channels (intended as the ones used for the cell planning regardless if they are with same or different polarisation) available to the operator are assumed to be equal to four. This assumption depends on the number of slots available to the operator, on the channel size of the system used and on the requirement on the minimum sector sizes (only the vertical polarisation could be allowed)
- The number of terminals deployed per sector and per operator is assumed to be equal to fifteen. This assumption is considered reasonable for the common case in which the operators address the SME market segment. The addressing of the residential market could change the above figure. It is however worth noting that clustered residential users which share the same ODU terminal would not effect the interference probability evaluation.

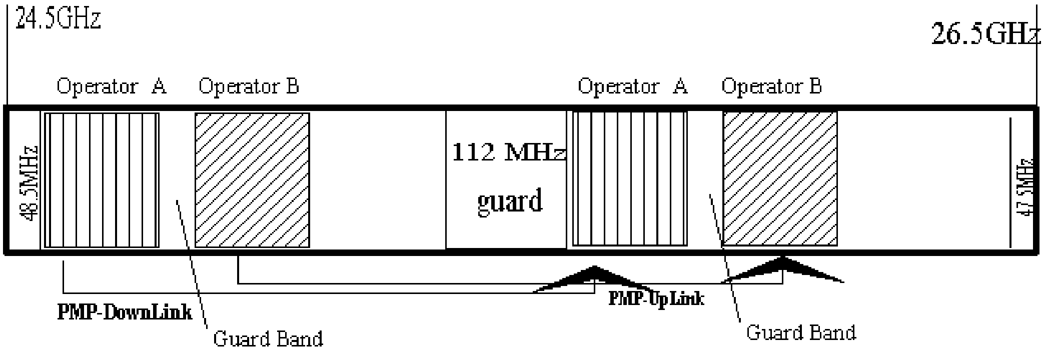
In addition, it is worth noting that for the purpose of this document all calculations are made by using the frequency of operation of 26GHz and by evaluating the attenuation, due to the atmospheric absorption, according to the Rec. ITU-R P.676-3 annex 2 and according to the following data:

- Pressure: 1013 hPa
- Temperature: 15° C
- Water vapour: According to ITU-R Rec. P.835-2, § 3.1 (summer profile)
- Water vapour density: related to the 0-400m antenna altitude and to the middle latitude (45°).

## 3 "SAME AREA - ADJACENT FREQUENCY BLOCKS" INTERFERENCE SCENARIO

We assume that operators A and B own two adjacent frequency block in the same area and they use same or different channel plans, as allowed by T/R 13-02. The following analysis evaluates the interaction between the upper channel of operator 1 and the lower channel of operator 2, i.e. the real adjacent channel inside the adjacent block (see Figure 2).

**Figure 2**




We also assume to state that one of the sub-bands ( lower) is for downlink purposes only, while the other sub-band (upper) is for uplink purposes only. This is needed in order to assume that, in the FDD case, the hub to hub and terminal to terminal interference scenarios can never happen.

We consider, as worst case for PMP systems, the interference scenario shown on Figure 3, where the terminal B, connected to the hub B (owned by operator B), is interfered by hub A (owned by operator A). The scenario is considering the downlink interference case but the uplink scenario is reciprocal or even better when ATPC is considered. ATPC is instead not considered in the downlink direction.

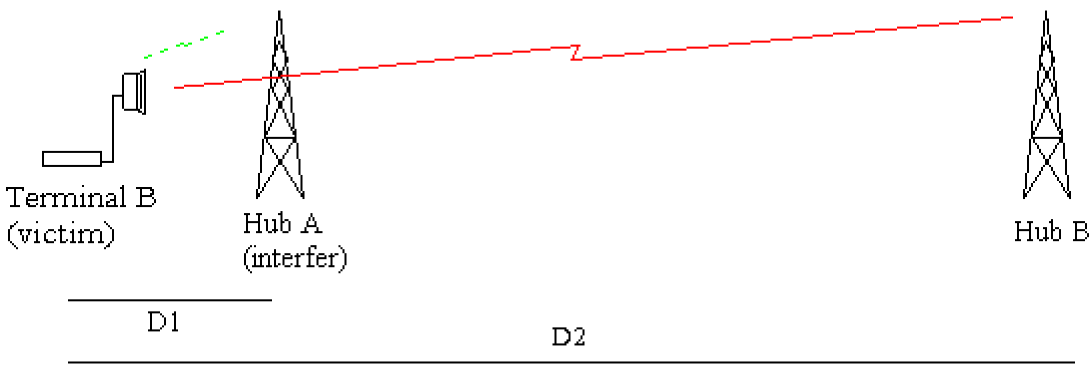



**Figure 3**

D1 is the minimum distance to be calculated – referred to as "$d_{min}$" in the text – in order to satisfy the wanted planning criteria; D2 is the service radius (see annex 2).

## 3.1 Description of the methodology used

A number of methods have been alternatively used to assess the severity of interference in the hub to terminal scenario.

These are:
- Interference Area (IA), used for the hub to terminal scenario
- Interference Scenario Occurrence Probability (ISOP), used for the hub to terminal scenario
- Monte Carlo (MC), used for the terminal to terminal scenario
- Worst Case (WC), used for the hub to hub scenario

In the hub to terminal scenario unacceptable interference occurs when the Terminal Stations (TS) are placed only in certain areas of a cell or sector. The Interference Area (IA) is the size of this area relative to the total cell or sector area.

The ISOP and the IA methods are typically used for the analysis of the hub to terminal interference scenario. They start from opposite direction but reach very similar results and each can be considered as a check on the other. The ISOP method starts from an estimation of the interference probability assumes a reasonable probability requirement and, on this basis, evaluates the NFD (Net Filter Discrimination) and so the guard band which satisfies the requirement itself.

The IA method starts from the assumption about the guard band, and so the NFD value, which is reasonably required, and, on the basis of it, evaluates the interference area and the interference probability. It also uses a Monte Carlo method to estimate the IA based on a piecewise linear approximation of actual antenna patterns.

A Monte Carlo (MC) method is used to evaluate interference probabilities for the case of interference between terminals (TDD-FDD, or TDD-TDD systems). This case is not readily amenable to analysis. Terminals are placed at random in the interacting cells or sectors, and the interference between each pair of terminals evaluated. Statistics are computed based on the number of interacting pairs and the total number of terminals.

The above methods are relevant to the low interference probability that is expected in scenarios where the interference depends on the random locations of the terminals on customer premises, e.g. the TS to CS (hub) interference scenario. The hub to hub (or CS to CS) scenario is instead analysed according to the Worst Case method, which chooses system deployment parameters to ensure that interference is always below a set threshold for all cases.

## 3.2 The hub to terminal interference scenario

The hub to terminal and terminal to hub interference scenario is verified in case of FDD, TDD and mixed TDD/FDD systems deployments.

### *3.2.1 The Interference Scenario Occurrence Probability (ISOP) method*

The ISOP method evaluates the guard band required in order to meet an interference probability lower than a certain value.

It is assumed that 1% is the ISOP requirement to be acceptable.

Note that, in the hub to terminal interference case, the 1% ISOP means that one terminal station every one hundred could experience interference problems (C/I less than the target).

These interference problems can possibly be counteracted by:
- Changing the frequency of operation (easier when the operator has more than one available channel per sector)
- Connecting the TS to a different hub (but it can decrease the availability)
- Moving the TS antenna along the roof
- Deactivate the terminal, when all the above methods are useless.

The probabilistic ISOP approach is used for the hub to terminal case but not for the hub to hub case. The reason is that the hub to hub interference scenario is the most dangerous since it can create a complete sector blocking to both neighboring operators. The ISOP method and the possible countermeasures, described above, cannot be applied to the hub to hub scenario, for which a worst case approach is judged more suitable.

We also note that to reduce the ISOP requirement means increasing the guard bands and/or decreasing the max allowed EIRP.

### *3.2.1.1 The procedure used*

This section describes the procedure used for the estimation of the guard band:

1. The starting point is the definition of the interference reference model based on the assumptions described above.
2. According to the define model you evaluate the interference scenario occurrence probability (ISOP). It is a function of the interference area, #of terminals, #of channels/sector, etc.
3. Define the ISOP requirement. The analysis assumes as acceptable an ISOP requirement equal to 1%.
4. From the estimated interference area, you find the minimum victim to interference distance corresponding to the 1% ISOP target.
5. From the estimated minimum distance and according to the assumed system parameters you can evaluate the interference level.
6. From the calculated interference level and according to the carrier to interference requirement (e.g. the one which gives 1 dB degradation @10E-6), you evaluate the Net Filter Discrimination (NFD) requirement.
7. From the above calculated NFD requirement and according to the table reported in annex 1, you finally evaluate the guard band required for a reasonable interference free uncoordinated deployment

### *3.2.1.2 The reference model*

In this section we evaluate the occurrence probability of the hub to terminal scenario, drawing a possible reference model as the one shown in Figure 4.

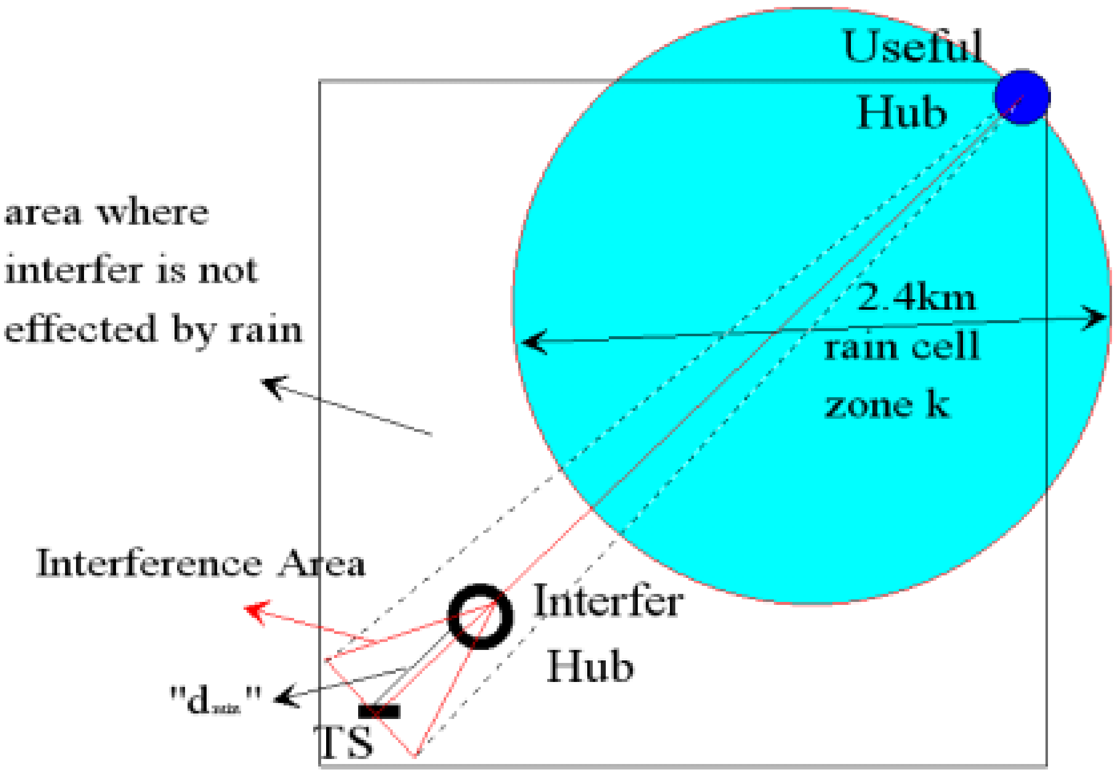



**Figure 4: Interference scenario reference model**

The above figure shows a radio sector of diagonal equal to 3.6 km, related to the coverage range of a 28MHz channel size system with the assumed system parameters (see annex 2).
It also shows a typical rain cell diameter Dc, evaluated as a function of the rainfall rate R(mm/h), according to ITU-R P.452-8, appendix 3, annex 1.
For the rain zone k: Dc = 3.3 x R^-0.08 = 2.4 km.
The rain cell has been placed (worst case) in such a way that the circumference is centred along the sector diagonal and tangent to the sector corner where the “useful” hub is located.

There is an area inside the sector where the interference is not affected by the rain attenuation, while the useful signal is. This is the worst situation and the one on which we will concentrate as it is the one where interference in terms of insufficient C/I is likely to occur (instead, when C and I are equally attenuated, the C/I is preserved).
The Interference Area (IA) is the triangle with the summit in the interfering hub location and the apex angle approximated as the 3 dB terminal antenna beamwidth angle.

The probability of the above hub to terminal interference scenario is evaluated as following:
ISOP = $(1-(1-P_1)^{Nt}) \times P_2 \times P_3$ (1)
where:

$P_1$ is the probability of having a terminal inside the Interference Area. In practice $P_1$ is the ratio between IA, defined as the area of the triangle (Area_triang) of height "$d_{min}$" and apex angle (θ), and the whole sector area (Area_sect).
$1-(1-P_1)$^Nt is the probability that at least one terminal fall into the interference area when there are Nt terminal stations (TSs) per sector per operators,

$P_2$ is the probability that the interfering hub lies in the rain free area of the sector. The area affected by attenuation is instead defined as "Area_rain",

$P_3$ is related to the mutual cell planning deployment carried out by the neighbouring operators. It is the probability that one interfering hub lies in each useful sector and uses a channel, which is adjacent and co-polar to the victim channel. $P_3$ depends on the number of available channels per operators and on the relative coverage and cell planning deployments. For square sector deployments, $P_3$ equals to [2/(Reuse_fact*Nch)] x [($d_b$/$d_a$)^2/4], where Reuse_fact is the sector frequency reuse factor and Nch is the number of different carriers, with single or double polarisation (here defined as available channels) used in the cell planning. The terms $d_a$ and $d_b$ are respectively the max coverage ranges achievable by the systems operated by the neighboring operators. In the present analysis the reuse factor is assumed to be 1 and $d_b = 2*d_a$ (see annex 3 for further explanation).

Given that :

$$\text{ISOP}=\left[1-\left(1-\frac{Area\_triang}{Area\_\sec t}\right)^{Nt}\right]*\frac{Area\_set-Area\_rain}{Area\_\sec t}*\frac{2}{\text{Re}use\_fact*Nch}*\frac{(d_b/d_a)^2}{4}$$

and

Area_triang = $(d_{min}^2)*\tan\theta/2$,

assuming that the required ISOP is 1%, the neighbouring operators own 4 channels and
deploy 15 terminals per sector, the frequency reuse factor is one and $d_b=2*d_a$, we can derive that:

$$d_{min}=\sqrt{\frac{\left(1-\sqrt[Nt]{1-\left(\dfrac{ISOP}{\dfrac{Area\_set-Area\_rain}{Area\_\text{sect}}*\dfrac{2}{\text{Re}use\_fact*Nch}*\dfrac{(d_b/d_a)^2}{4}}\right)}\right)*Area\_\text{sect}}{\tan(\theta/2)}}=0.7\text{ km}$$

Hence, $d_{min}$ = 0.7 km is the minimum distance above which the probability of suffering an interference is lower than the assumed target value, here defined as 1%.

### *3.2.1.3 The ISOP sensitivity to deployment parameters*

This section analyses the ISOP sensitivity to the deployment parameters described in the section above, assuming that dmin is equal to 0.7 km.

The Figure 5 shows the ISOP variation against number of terminals deployed per sector per operator when the number of channels per operator ranges from 2 to 8. Note that the frequency reuse factor is one and $d_b$=2*$d_a$.

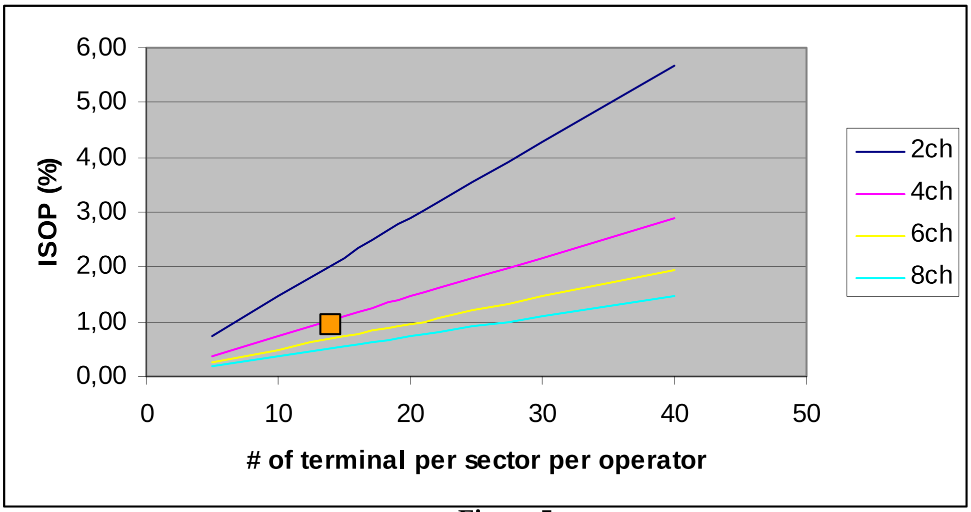



**Figure 5**

The Figure 6 shows the ISOP variation against number of terminals deployed per sector per operator, when each operator owns four channels, the frequency reuse factor ranges from 1 to 2 and the systems deployed by the neighbouring operators perform the same or double coverage ranges.

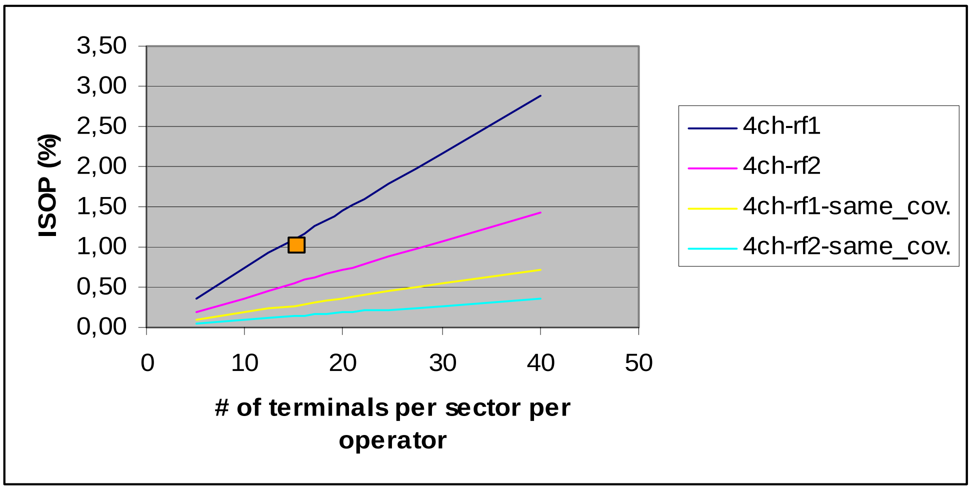



**Figure 6**

#### *3.2.1.4 The guard band evaluation for the ETSI EN 301 213-2,-3 (4 level modulation type) systems*

Using the system parameters described in the table 2 of the annex 2, we can evaluate the interference level, at the terminal B antenna connector (see Figure 3), when the interfering source is at a distance equal to 0.7 km, which is the minimum distance corresponding to the 1% ISOP. The value of the interference is evaluated according to the free space loss criterion as expressed in the following formula:

$$I = Pout + Gt + Gn - 92.4\text{ dB} - 20*LOG(F) - 20*LOG(d_{min}) - Atm \qquad (1)$$

where F is the frequency of operation, hereby 26 GHz, and
Atm is the atmospheric absorption.
Note that:

$$I\_0.7km = -40.6\text{ dBm}$$

Considering that C/I_adj is the carrier to interference ratio resulting when the interference is not co-channel and that C/I_th = C/I_adj + NFD and C/I_adj = C_th – I, the NFD level needed in order to meet the required C/I threshold, is:

$$NFD=C/I\_th - C\_th + I \qquad (2)$$

The NFD required against the different system capacities is shown in the table 1:

| *System capacity* | *NFD (dB)* |
|---|---|
| 4Mb/s (3.5MHz) | 66,4 |
| 8Mb/s (7MHz) | 63,4 |
| 16Mb/s (14MHz) | 60,4 |
| 34Mb/s (28MHz) | 57,4 |

**Table 1: The required NFD**

From table 1 and from the NFD table attached in the annex 1, we can evaluate the guard band requirements:

| PMP Vs PMP compatibility | | **Required Guard Band (MHz)** | **Required Guard Band (N° of CHs*)** |
|---|---|---|---|
| ***Victim*** | ***Interferer*** | | |
| 4 Mb/s (3.5 MHz) | 4 Mb/s (3.5 MHz) | 5,25 | 1,5 |
| | 8 Mb/s (7 MHz) | 10,5 | 1,5 |
| | 16 Mb/s (14 MHz) | 18,75 | 1,3 |
| | 34 Mb/s (28 MHz) | 36,25 | 1,3 |
| 8 Mb/s (7 MHz) | 8 Mb/s (7 MHz) | 9 | 1,3 |
| | 16 Mb/s (14 MHz) | 17,5 | 1,3 |
| | 34 Mb/s (28 MHz) | 34,5 | 1,2 |
| 16 Mb/s (14 MHz) | 16 Mb/s (14 MHz) | 16 | 1,1 |
| | 34 Mb/s (28 MHz) | 33,5 | 1,2 |
| 34 Mb/s (28 MHz) | 34 Mb/s (28 MHz) | 30 | 1,1 |

**Table 2: Guard band evaluation**

* Guard band defined in terms of the widest channel.

According to the table 2, we can conclude that the guard band requirement can be approximated (rounded down) to 1x28 MHz slot, relevant to the worst case where one of the two systems has 28MHz-channel size. It is worth nothing that the 1% ISOP target, above assumed as initial target, should be increased to about 2% in order to precisely achieve the result of 28 MHz guard band.

The channel size considered for the 4, 8, 16 and 34 Mb/s systems is respectively 3.5, 7, 14 and 28 MHz, in accordance with the CEPT T/R 13-02 channel plan.
It is worth noting that the lower capacity systems require, in terms of number of channels, as shown in table 10, a guard band larger than the one required by the higher capacity systems. Indeed the ETSI EN 301 213 standard defines same radio frequency tolerance (+/- 15 p.p.m.) for all different system capacity and channel sizes with the direct consequence that the transmission and receiver masks are, in proportion, larger for the lower capacity systems. The final result is that NFD figures are higher for higher capacity systems and consequently the guard band requirements are, in terms of n° of channels, lower for such systems.
This consideration also applies to the sections below.

In conclusion, it is recommended the adoption of one 28 MHz guard band for uncoordinated operations, in order to counteract the hub to terminal interference.

*3.2.1.5 Example of interference effects*

This section shows, as for a practical example, the effect of the interference for a case where the guard band between two operators are not provided or provided in a insufficient way.

We assume that an operator with 4 Mb/s system (3.5 MHz channel size) provides 3.5 MHz guard band towards a neighboring operator operating a 16 Mb/s system (14 MHz channel size).

| Interferer distance | 16Mb/s system | | 4Mb/s system | |
|---|---|---|---|---|
| | clear sky | rain | clear sky | rain |
| 700m | 30.6 | 10.6 | 8.6 | -11.4 |

**Table 3: C/I (dB) figures at the victim receiver**

The result, expressed in the table 3, shows that the 4Mb/s system would suffer severe availability and quality degradation with a consequence of impossible operation. The 16Mb/s system would suffer availability degradation but the quality would be quite good (<30 dB) for high percentage of time (99.9x%) and locations (99%).

### *3.2.2 The Interference Area (IA) methods*

The IA method is related to the ISOP method described above in that both begin with the concept of determining an area within the victim cell in which the interference power received from the interfering CS by a TS, whose antenna can receive in-band signals from both, is above a set threshold. Again this threshold is set 21 dB below the specified receive level for $10^{-6}$ BER. The IA is computed for specific antenna patterns and various combinations of guard bands and channel assignments as appropriate. Thus the IA calculation starts with a guard band (and therefore NFD) assumption and derives the Interference Area, the reverse procedure to the ISOP method presented previously. It also allows the effect of specific antenna patterns to be evaluated.

The IA is equivalent to the probability that a single terminal placed anywhere in the victim cell will suffer threshold degradation as a result of the interference. The overall ISOP for a given guard band can be computed by:

- calculating the individual ISOPs for each possible channel and polarisation assignment assuming a number of terminals per cell;
- taking a weighted average of the ISOP values for the various possible frequency assignment and cell deployment cases on the basis of their probabilities.

Clearly the ISOP values estimated by this procedure should be equivalent to those estimated by the previous method for the same guard band, except for the effect of different antenna patterns.

*3.2.2.1 Geometry*

Figure 7 shows the geometry assumed for victim cell and interfering CS.

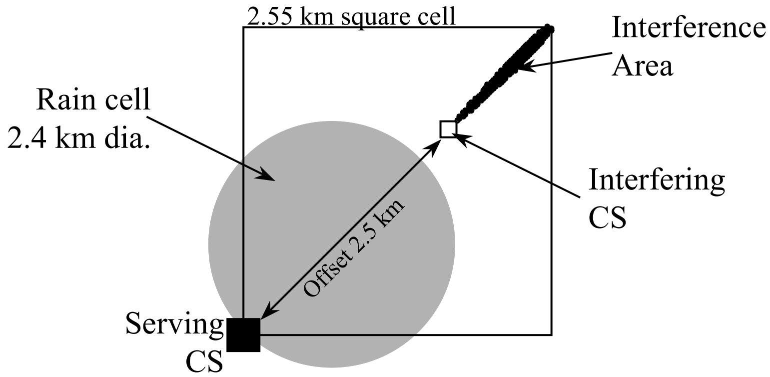



**Figure 7: Geometry for IA computation**

The serving CS is placed at the corner of a square sector of diagonal 3.6 km, and the interfering CS is placed at an offset of 2.5 km. It is assumed that the interfering CS is pointed in the same direction as the serving CS so that TSs in the Interference Area have visibility of both central stations. Both the serving and interfering CS have 90° sectored antennas.

The shape of the interference area shown (which is based on a real computation) is determined by the TS antenna pattern, the gain of the CS and TS antennas, and the power transmitted by the interfering CS. The IA may be bounded at its outer end by the shape of the cell since by definition no terminals will be placed outside the cell boundary.

The offset of 2.5 km places the interfering CS just outside the worst-case rain cell and has been determined by several numerical experiments to be the worst case. If it is placed closer to the serving CS, then the interference power begins to be attenuated by the rain; if it is placed further away then an increasing proportion of the IA is outside the cell boundary. Thus the IA is approximately maximised for the offset shown. The sensitivity of the IA to different offsets (ignoring rain effects) is evaluated below.

#### *3.2.2.2 Calculation method*

The calculation method used is a straightforward Monte-Carlo analysis, based on a polygonal numerical representation of the TS antenna RPE pattern[1]. This allows the effect of different patterns on the IA to be evaluated. The method proceeds as follows.

- A large number of random TS trial locations (typically $10^4$ - $10^5$) is generated in the cell;
- All locations which are not within the 90° sector width of the interfering antenna are discarded;
- For each remaining location, assuming it is boresight to the serving CS, the angle between the boresight and the interfering CS is calculated;
- The gain of the TS antenna is computed for this angle by linear interpolation on the polygonal representation;
- The received interference power is computed, given the NFD for the given frequency assignments between server and interferer, the antenna gains, and the interferer transmit power;
- If the interference power is above the victim system threshold, a count of points in the IA is incremented.

Finally, the IA is computed as the ratio of the total count of such points to the total number of trial locations.

#### *3.2.2.3 Antenna RPEs used*

A number of different RPEs have been analysed, as shown in the table below.

| Type | Comments |
|---|---|
| A | ETSI TS1 antenna described in EN 301 215-2; Figure 8(A), but with 35 dB assumed gain. |
| B | Hypothetical antenna based on A with improved side-lobe performance and more realistic nose shape; Figure 8(B). |
| C | TDMA antenna assumed in TM04069; Figure 9(C). |
| D | Idealised “rectangular” antenna of 4° beamwidth; Figure 9(D). |
| E | IEEE 802.16 directivity Class 2 26 GHz antenna; Figure 10(E)[2] |

**Table 4: Antenna types**

[1] RPEs can be fed in as masks, as published in (e.g.) ETSI specifications or as pointwise digitised patterns, the points being assumed to be connected by straight line segments.

[2] This is included as representative of an antenna being studied in another standards body studying FWA coexistence issues.

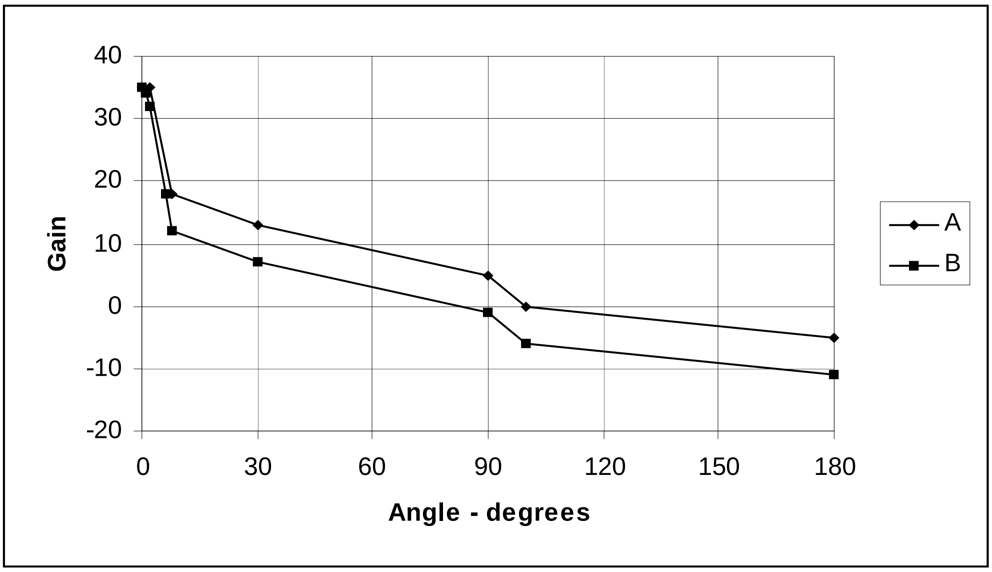



**Figure 8: ETSI and modified ETSI RPEs**

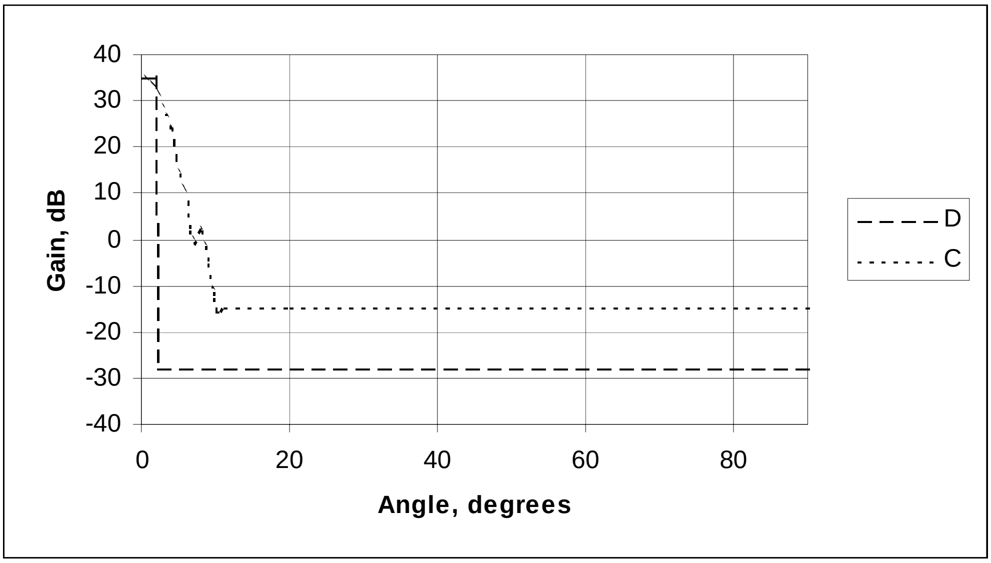



**Figure 9: TM04069 antenna (C), and "perfect" equivalent (D)**

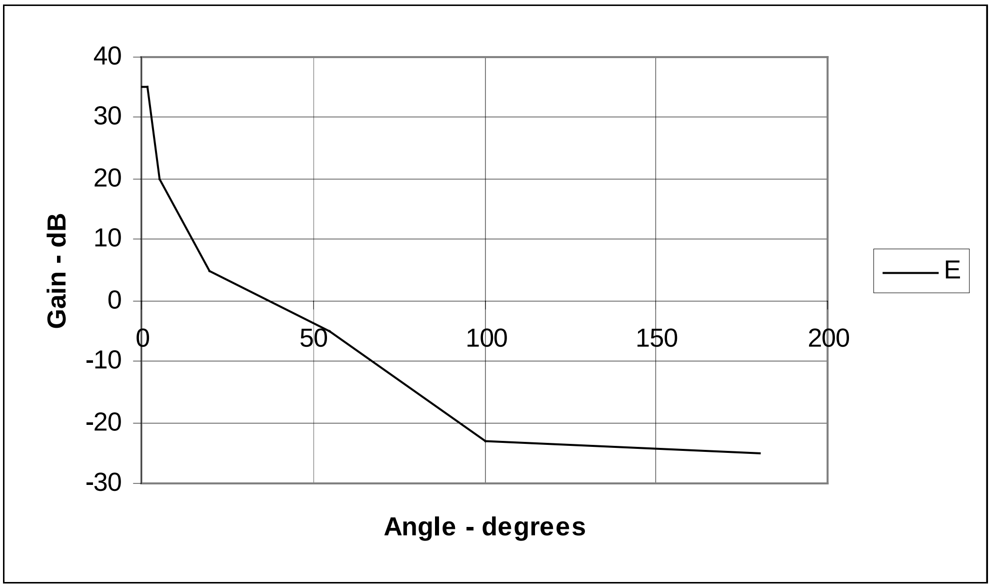



**Figure 10: IEEE 802.16 26 GHz Type 2 antenna RPE**

### *3.2.2.4 Results*

Table 5 gives the computed values for IA and ISOP for all the above antennas, for the reference cell size of 3.6 km diagonal and for 21 dB Threshold/Interference level. For each case 100,000 Monte-Carlo trials were used. Where necessary, because the absolute maximum gain of the various antennas differ, for each computation the interferer transmit power was set so that the maximum (boresight) received power was the same, corresponding to a transmit power of 24 dBm and a TS antenna maximum gain of 35 dB.

The ISOPs are computed on the assumption that with the given guard band significant interference only occurs when the victim and interfering system channels have the minimum spacing (56 MHz in this case) and are co-polar; and that the size of the interfering cell is half that of the victim. These assumptions correspond to those in the above ISOP analysis. From the assumptions in the previous ISOP analysis it can be shown that ISOP is then given by the formula:

$$\text{ISOP} \quad = \quad 0.2446\,(1 - [1 - \text{IA}]^{N_t})$$

where we assume that $N_t$ is 15.

| | NFD = 54 dB | | NFD = 57.5 dB | |
|---|---|---|---|---|
| **Antenna type** | **IA - %** | **ISOP - %** | **IA - %** | **ISOP - %** |
| A | 1.38 | 4.60 | 0.58 | 2.03 |
| B | 0.78 | 2.70 | 0.31 | 1.1 |
| C | 0.75 | 2.6 | 0.3 | 1.07 |
| D | 0.71 | 2.49 | 0.32 | 1.16 |
| E | 1.14 | 3.85 | 0.45 | 1.59 |

**Table 5: IA and ISOP for various antennas**

It can be seen from these results that the IA varies from 0.71% for the “ideal” antenna which has a “rectangular” RPE pattern to 1.38% for the worst case, the ETSI TS1 antenna. This is a nearly 2:1 change – as might be expected the antenna pattern is a critical factor in determining the interference area.

Interestingly, the antenna assumed in TM04069 is very nearly as good as the “rectangular” antenna, type D. Type E, the IEEE 802.16 pattern, gives intermediate results.

The ISOP value computed from the IA for NFD=54 dB are significantly larger than 1% as would be expected since the 1% value led to a required NFD of 57.5 dB. Inserting this 57.5 dB value in the Monte Carlo simulation for 28 MHz systems and using antenna type D (which is equivalent to the antenna assumption in the ISOP method) results in an IA of 0.32%; ISOP o 1.16%. Thus the ISOP calculation by the IA method is close to that by the previous method. The relatively small difference is because assuming an ideal antenna pattern (as is done in the ISOP method), the apex angle of the interference area is slightly larger than the beamwidth as is clear from a close examination of the geometry.

Figure 11 shows the actual shape of the IA for antenna type A. The effect of the side-lobes, causing a "thickening" of the IA around the interfering CS, can be clearly seen.

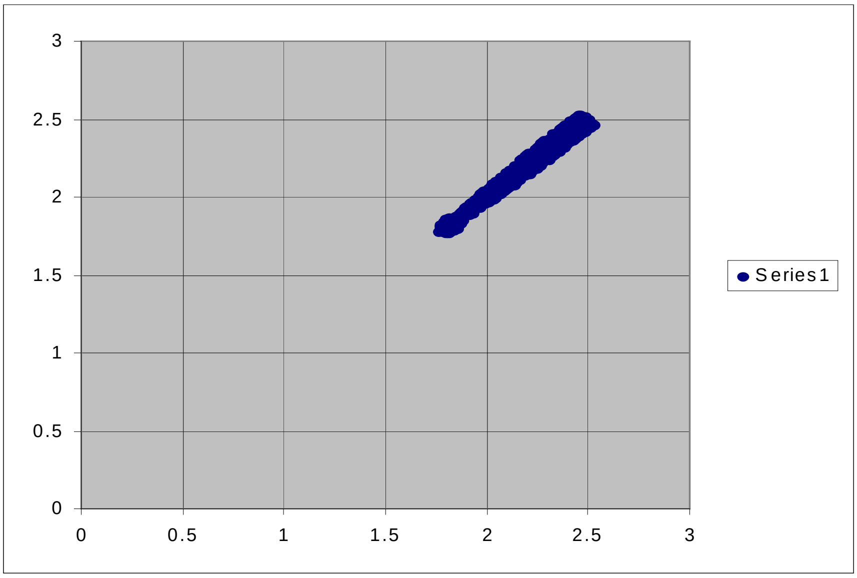



**Figure 11: The Interference Area for Antenna Type A**

It is useful to explore the sensitivity of IA and ISOP to other parameters by the Monte Carlo method. As described previously, the reference scenario assumes that the interfering cells have half the size of the victim. If the interfering cells had the same size, but were designed to achieve the same availability as before by increasing the transmit power by 6 dB, then the IA would increase to 1.28%, a factor of 1.71. However, the number of interfering cells in the same area would decrease by a factor of 4, and so therefore would the probability normalising factor in the calculation. The corresponding ISOP value will then be 1.08%.

The sensitivity to interferer power depends on the TS antenna type. With antenna type D, a 6 dB power increase *increases* the IA by a factor 1.4; whilst a 6 dB increase *decreases* the IA by a factor of 4.4.

Next we explore the effect of dissimilar systems. We assume that the interferer is a 28 MHz TDMA system and the victim a 3.5 MHz TDMA system, this combination representing the worst case as the victim system has the lowest threshold. The victim system has the same cell size, 3.6 km diagonal; and the interferer again uses cells half the size. (The 3.5 MHz system would use the improved link budget to provide better availability) We assume a guard band of 28 MHz again, and obtain from the tables of Annex 1 an NFD of 56 dB. Assuming TS antenna type D on the victim TS and a required threshold of – 86 dBm we obtain an IA of 1.55% and ISOP of 5.11%. A more realistic antenna, the IEEE Type E, gives an IA of 2.07% and ISOP of 6.6%.

Finally we evaluate the IA for different offsets. The calculation ignores the effect of rain fading. The figure below plots IA and ISOP against offset.

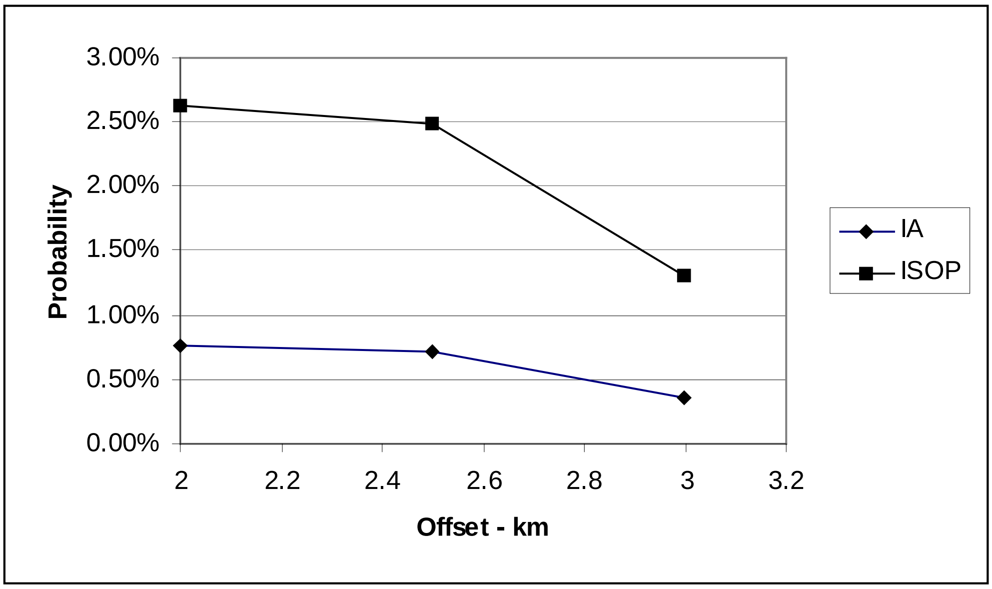



**Figure 12: Probability vs. offset**

This calculation of course ignores the practical effect of the rain fade (in weather conditions where the interference becomes significant) which would attenuate the interference as well as the signal for offsets below 2.4 km.

#### *3.2.2.5 Discussion*

This section has presented the Monte-Carlo method of computing the probability of a TS suffering co-channel interference greater than a set margin above system threshold. The method assumes a given Net Filter Discrimination between the systems and uses measured or theoretical TS antenna RPE patterns. It also applies similar cell deployment probability assumptions to compute the corresponding ISOPs. It should thus represent real cases of interest.

Results have been presented for the reference configuration giving IA for a range of antennas which are thought to be typical of realistic P-MP systems. These range from the ETSI TS1 antenna described in EN 301 215, through improved antennas including the IEEE 802.16 26 GHz Type 2 pattern, the measured pattern reported in TM040609, to an idealised "brick wall" antenna. The analysis has been carried out assuming TDMA systems with channel widths of 28 MHz (interferer)/28 MHz (victim); and 28 MHz (interferer)/3.5MHz (victim).

Typical values of IA range from 0.7 - 2 % on the assumption of a 28 MHz guard band resulting in an NFD of about 54 - 56 dB. Bearing in mind that the effect of the interference is to degrade the system threshold by about 1 dB but only in severe rain faded conditions, it may be concluded that this guard band is probably acceptable for most cases. The ETSI TS1 antenna gives the worst results.

It is shown that the corresponding ISOP values for 28 MHz guard-band could be larger than the method presented in Section 4.2.1, typically ranging from 2.5 – 6%. This is because the NFD for the actual recommended guard band of 28 MHz is lower than the figure derived from the ISOP calculation of Section 4.2.1; and because the geometry of that analysis is slightly simplified. Repeating the IA calculations using the Monte-Carlo simulation but assuming an NFD of 57.5 dB and an appropriate antenna gives results in good agreement with the ISOP method.

### 3.3 Hub to hub interference scenario

The hub to terminal and terminal to hub interference scenario is verified in case of TDD and mixed TDD/FDD systems deployments. Hence the FDD systems are not affected.

### *3.3.1 The hub to hub minimum coordination distance*

The hub to hub interference scenario, see the reference model in Figure 13, is the most dangerous since it can create a complete sector blocking to both neighboring operators. The ISOP method and the possible countermeasures, described in 4.2.1, can be considered insufficient when applied to the hub to hub scenario. For this reason, in the table 6, it is evaluated the minimum "coordinated" distance, according to a worst case criterion, required for safe operations.

| | | **Minimum distance with 1Ch guard* (km)** | **Minimum distance with 28 MHz guard (km)** | **Minimum distance with 2Ch* guard (km)** |
|---|---|---|---|---|
| ***Victim*** | ***Interferer*** | | | |
| 4Mb/s (3.5MHz) | 4Mb/s (3.5MHz) | 0,412 | 0,016 | 0,052 |
| | 8Mb/s (7MHz) | 0,462 | 0,018 | 0,029 |
| | 16Mb/s (14MHz) | 0,327 | 0,018 | 0,018 |
| | 34Mb/s (28MHz) | 0,412 | 0,412 | 0,018 |
| 8Mb/s (7MHz) | 8Mb/s (7MHz) | 0,260 | 0,016 | 0,041 |
| | 16Mb/s (14MHz) | 0,232 | 0,032 | 0,033 |
| | 34Mb/s (28MHz) | 0,260 | 0,260 | 0,018 |
| 16Mb/s (14MHz) | 16Mb/s (14MHz) | 0,184 | 0,041 | 0,041 |
| | 34Mb/s (28MHz) | 0,207 | 0,206 | 0,033 |
| 34Mb/s (28MHz) | 34Mb/s (28MHz) | 0,184 | 0,184 | 0,021 |

**Table 6: minimum distance for safe-uncoordinated operations (km)**

(*) Guard band expressed in terms of the larger channel.

Using the system parameters described in the table 2 of the annex 2, the minimum distance is evaluated as follows.

Considering that:

$$I = C\_th - C/I\_th + NFD$$

and

$$I = Ptx + Gt + Gn - 92.4 - 20\log(F) - 20\log(Dmin)$$

we can derive:

$$Dmin = 10\text{^} (-(Cth - C/I\_th + NFD - Pout - Gt - Gn + 92,4 + 20 * LOG(F))/20) \qquad (3)$$

where F is the frequency of operation, hereby assumed as 26 GHz.

In conclusion, it is recommended the adoption of two 28 MHz channel guards for completely safe and uncoordinated operations, in order to counteract the hub to hub interference. The 28 MHz guard band is indeed required in the worst case scenario, which is the one where a 28 MHz system interferes a 3.5 MHz system, as shown in the table 7.

As alternative when co-ordination is possible, a minimum hub to hub distance of about 500 m, associated with a single guard band, is recommended.

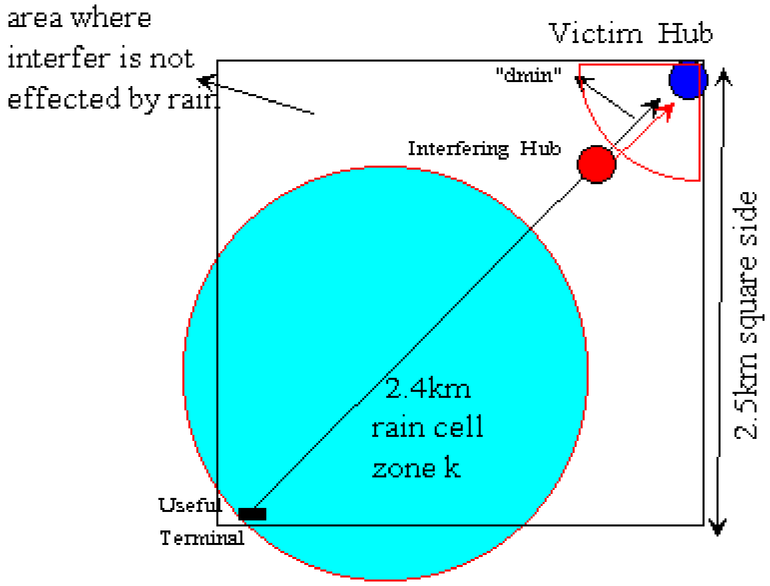



**Figure 13**

### 3.4 The terminal to terminal interference scenario

The terminal to terminal and terminal to hub interference scenario is verified in case of TDD and mixed TDD/FDD systems deployments. Hence the FDD systems are not affected.
This interference can arise because two terminals may have near-boresight visibility of each-other. If both are TDD then they will mutually interfere; if one is FDD and the FDD downlink channel is adjacent to the TDD channel, then the TDD terminal will interfere with the FDD one; and if the TDD channel is adjacent to the FDD uplink channel; then the FDD will interfere with the TDD.

Intuitively, because both terminals have highly directional antennas, the probability of such interference is low. However if the two cells in which they lie are overlapping, the terminals could be quite close together; and since both have directional antennas the EIRP from the interferer may be higher than it would be from an interfering CS (depending on power control setting); potentially resulting in severe interference.

The geometry of the interference scenario is rather complicated and it seems to be difficult to find an analytical formulation. Therefore a Monte Carlo simulation has been developed which generates statistics of the probability for mutual visibility of the TSs and cumulative probability distributions for the carrier to interference ratio.

For small values of cell overlap, where any pair of interfering TSs must be very close and the interfering TS must be transmitting at maximum power, low values of C/I can arise; made worse by rain fading. However the probability of any interference conflict arising is extremely low (of the order of 0.02% for the scenario investigated). At the most one channel guard band will be needed; and even adjacent channel operation may be possible depending on the operators' judgement of the acceptability of the probability level.

The maximum probability of interference arises when the TSs are served by co-sited CSs. In this case however the C/I ratio distribution is such that virtually no terminals will experience a C/I below threshold (~ 21 dB) even with adjacent channel operation. Rain fading will either improve the C/I or leave it unaffected.

*3.4.1.1 The method*

Figure 14 shows the geometry assumed for the simulation.

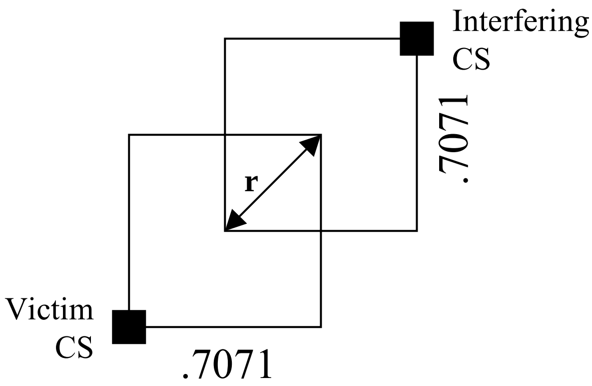



**Figure 14: Interference geometry**

Two equal-sized, square FWA sectors are located in the worst case such that they share a diagonal, but overlap. Both sectors are assumed to have unity diagonal, so that their dimensions are $1/\sqrt{2} \times 1/\sqrt{2}$. The overlap parameter r can vary from zero, in which case there is no overlap and no possibility of TS – TS interference; to unity, when the interfering CS is on the corner of the victim sector diagonally opposite the victim CS; to 2, when the CSs are co-sited; to any greater value

In order to interfere, two TSs have to be placed so that each lies in the antenna beam of the other. Also, each TS has to point directly at its serving CS. It is immediately apparent that, for small beam-widths, interfering pairs of TSs will lie close to the mutual cell diagonal.

The following Monte-Carlo procedure is used for simulation.

- A large number of trials is carried out, each trial simulating a complete roll-out of N terminals by each operator.
- For each trial, N terminal locations are chosen at random uniformly distributed in the victim sector.
- N terminal locations are chosen at random uniformly distributed in the interfering sector.
- A victim TS location is taken and every interfering TS location in turn evaluated to find out if it lies in the victim beam; if it does, then the victim location is tested to find out if it lies in the interfering beam; if it does, then 1 is added to the total number of interference conflicts.
- The previous step is repeated for each victim location until all have been considered.
- For each interfering pair the "geometric" carrier-to interference ratio, determined by  is calculated and the C/I distribution updated. The C/I calculation takes account of proportional power control in the interfering sector.

As well as the distribution the simulation computes the total number of terminal placements, M, which give rise to an interference conflict. Overall, if there are I trials and in each trial, each operator "rolls out" N terminals, then the total number of terminal placements is just $I.N^2$. Therefore the probability of conflict is just $M/(I.N^2)$.

*3.4.1.2 Simulation and results*

The simulation has been coded as a Visual Basic macro which runs as part of an Excel spreadsheet, allowing the results to be conveniently printed and plotted. The results below are for the following simulation parameters:

| | |
|---|---|
| No. of trials | 10.000 |
| TS antenna beam-width | 4° |
| No. of terminals per sector per operator | 15 |

Figure 15 plots the probability of interference conflict as a function of cell overlap over a range of **r** which is appropriate for same-area adjacent frequency interference.

It is immediately apparent that for most values of **r** the probability of conflict is very low, less than 1%. The probability peaks significantly around r = 2, the co-sited CS case, where the maximum probability is about 7.5 %. Whilst this probability is rather high, it is also important to examine the C/I distribution. The geometric C/I distribution is shown for 5 values of r from 0.5 to 2.5 in Figure 16.

The geometric C/I has to be adjusted by several factors to find the actual C/I in a given deployment:

- It must be decreased by the antenna gain differential between the TS and CS antennas.
- It must be increased by the normal ATPC power reduction at the cell edge.
- It is increased by the NFD between the interfering and victim systems in the case of same-area adjacent frequency operation.
- It is increased by any polarisation discrimination.

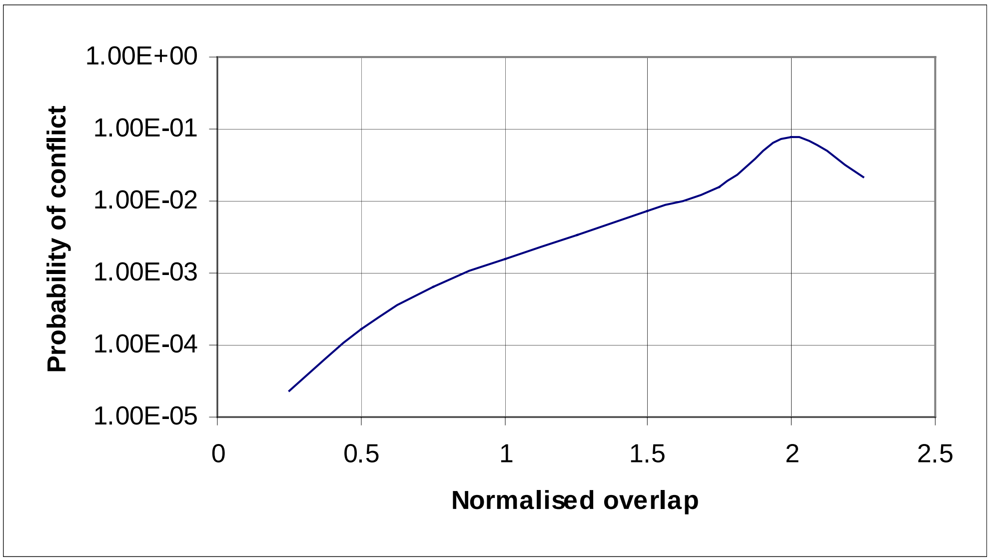



**Figure 15: Interference probability as function of cell overlap**

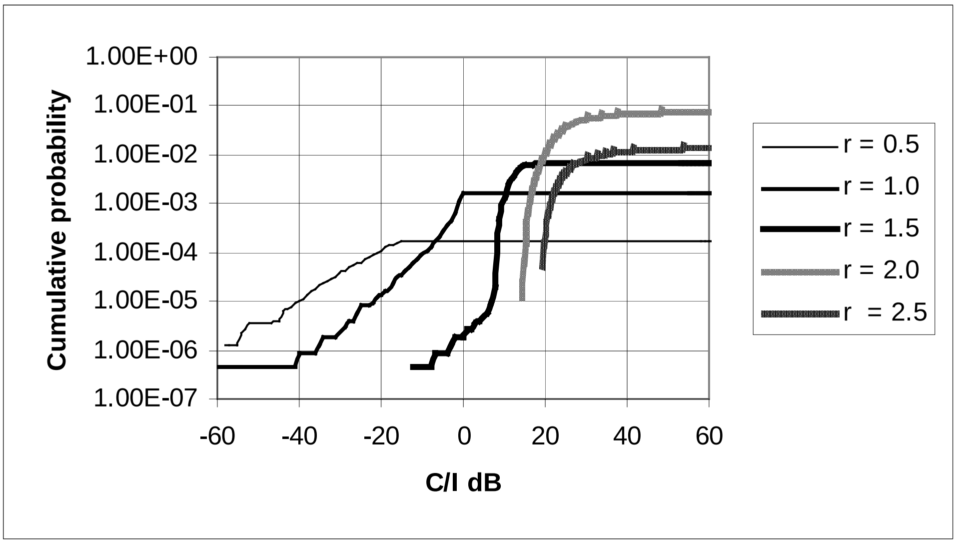



**Figure 16: Distribution of C/I ratio**

A typical antenna gain differential is 16 dB; and typical ATPC cell-edge power setting is 15 dB below the CS transmit power. These factors therefore nearly cancel. The NFD could be typically assumed to be 23 dB for adjacent channel, or 54 dB for one channel guard band, assuming 28 MHz channels and a TDMA-type system. In the worst case of uncoordinated operation we could assume co-polar operation.

In the worst interference distribution shown in Figure 17 therefore, for r = 0.5, where the knee of the C/I distribution occurs at about –10 dB, most of the TSs (absent rain fading) would experience a C/I of 43 dB or worse assuming one channel guard band (NFD 54 dB). In this case rain fading over the victim CS would fade the wanted carrier by up to 25 dB, reducing the C/I during the fade (for those TSs affected) to 18 dB. However, only 0.02% of TSs are affected! A 25 dB rain fade over the interfering cell will increase the TS transmit power by up to the ATPC cell edge setting, i.e. 15 dB with the assumptions above, reducing the C/I to 28 dB, but again for only 0.02% of terminals. Thus in probability terms, even adjacent channel operation could be possible.

For r = 2, the “co-sited” case, the knee of the C/I distribution is at about 15 dB. The clear sky C/I will then be 37 dB for adjacent channel operation, or 68 dB for one channel guard band. Because TS – TS interference demands nearly boresight alignment between the TSs concerned, and also the CS site, rain fading is virtually perfectly correlated between the links. A rain cell over the interfering sector will leave the interference power unchanged because of the ATPC, or reduced by up to the difference between the fade depth and the ATPC setting (typically 10 dB). At the other extreme, a rain fade over the victim cell will fade both the wanted signal and interfering signal equally, leaving the C/I unaffected. Overall the effect of rain fading on the co-sited scenario is benign to neutral, and adjacent channel operation should be possible.

The above results show that the TS – TS interference will not be the limiting factor for this interference scenario.

### *3.4.2 TDD or mixed TDD/FDD terminal-to-terminal and hub-to-hub co-siting interference scenario*

This scenario takes into consideration the case where two different operators have customers in the same building with a consequence of antenna installations in the same roof and the case where the hub co-siting, due to visual pollution reasons, is an obligation.
With two antennas installed close to each other, the isolation will depend on the relative position between the two antennas. In order to get isolation estimation, it will here be assumed that the antennas can be located next to each other, with their main beams pointing in the same direction.
Typical sidelobe level at 90° angle will be about –20 dB for both co- and cross-polarisation, so even if different polarisations are used about the same isolation levels will be obtained.
We assume the l antennas have an extension of 24 cm, corresponding to a farfield distance of about 10 meters at 26 GHz. As the farfield distance is that long, it will be very unreliable to draw any conclusions at all of isolation at distances closer than approximately 2-3 meters. At distances between 2-3 meters and 10 meters the calculated values could probably be used for rough estimations if a safety margin is included.
With the assumption of two antennas having a sidelobe levels of -20 dBi, installed in the farfield region of each other or having radiation behaviour as in the farfield, isolation versus distance will be as described in the following figure 17.

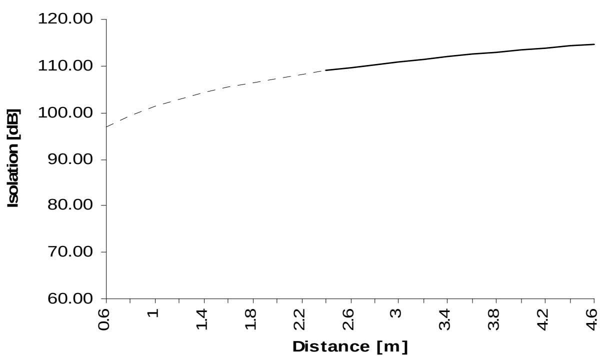



**Figure 17**

We can evaluate the isolation requirement (see table 8), for 1 dB threshold degradation at 10E-6, as following:
Isolation = - C_th + C/I_th + 24 dBm - NFD

| System | no guard band | 1 guard band | 2 guard band |
|---|---|---|---|
| 4Mb/s | 108 | 78 | 54 |
| 8Mb/s | 105 | 75 | 51 |
| 16Mb/s | 102 | 72 | 48 |
| 34Mb/s | 99 | 69 | 45 |

**Table 7: Isolation requirement (dB)**

Note that the guard band considered for the evaluation is the largest between the victim and the interfering ones.

From the results above, we can conclude that a minimum distance antenna installation is needed (> 10 m) when no guard band are provided but it is not needed when 2 guard band are in place.

Note that the guard bands are anyway required for the hub to terminal or hub to hub interference scenario as described in the sections above.

We have evaluated, as worst case, the deployment scenario described in Figure 18a since we have assumed that situations with worse relative antenna positions, relevant to the terminal antennas co-siting case, see Figure 18b, could be solved by a suitable and careful installation as shown in figure 18c.

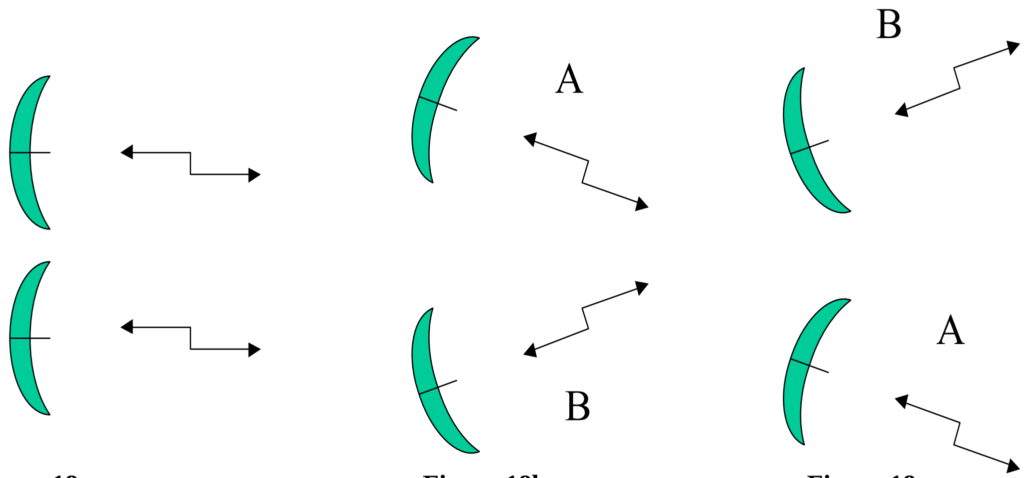



**Figure 18a** **Figure 18b** **Figure 18c**

### *3.4.3 Case of co-operative deployment*

#### *3.4.3.1 Co-siting or near co-siting*

This case is more favourable, as C and I are always affected in the same manner by the rain.
The co-operative deployment allows the best spectrum efficiency since it allows avoiding or reducing to a minimum the amount of guard bands. It also allows planning the system deployment according to the worst case criteria, minimising the ISOP.
It is worth noting that the co-siting or near co-siting co-operative deployment is valid for symmetric FDD systems only, since it is based on the assumption of up/down bands statement. This assumption cannot be applied to asymmetric FDD and TDD.

The table below shows the necessary guard bands between systems co-sited using different capacities and radiating identical EIRP. The guard bands may vary depending on the radiated power, the modulation schemes (different C/I required), error correction capability, actual mutual deployment, etc. The availability of the ATPC functionality in the uplink direction has been assumed.

The table 8 shows that the need for guard band, in case of site sharing, is none or reduced to a minimum.

| | | Required Guard Band (MHz) | Required Guard Band (N° of CHs) |
|---|---|---|---|
| ***Victim*** | ***Interfer*** | | |
| | 4Mb/s | 0 | 0 |
| 4Mb/s | 8Mb/s | 0 | 0 |
| | 16Mb/s | 0 | 0 |
| | 34Mb/s | 1.75 | 1x3.5 |
| | 4Mb/s | 0 | 0 |
| 8Mb/s | 8Mb/s | 0 | 0 |
| | 16Mb/s | 0 | 0 |
| | 34Mb/s | 0 | 0 |
| | 4Mb/s | 0.8 | 1x3.5 |
| 16Mb/s | 8Mb/s | 0.8 | 1x3.5 |
| | 16Mb/s | 0 | 0 |
| | 34Mb/s | 0.9 | 1x3.5 |
| | 4Mb/s | 2.5 | 1x3.5 |
| 34Mb/s | 8Mb/s | 1.75 | 1x3.5 |
| | 16Mb/s | 0.6 | 1x3.5 |
| | 34Mb/s | 0 | 0 |

**Table 8**

In case of co-operative deployment and using instead the near site sharing criteria the operators can, on case by case basis, evaluate the own need for guard band.

The table 9 considers that additional guard bands among allocated spectra can compensate system impairments (different EIRP and/or different modulation schemes) and/or allow ”near sites” deployment with no performance degradations. In order to read the table, let’s consider the fourth line in the case of 7 MHz guard band: in this case there are 30 dB of NFD and only 21 are needed for the C/I requirement. This means that 9 dB are still available in order to compensate a difference in terms of EIRP or modulation scheme in the case of co-siting. Alternatively, hubs may be spaced of 112 m realising near co-siting.

| | | NFD provided by 7MHz Guard Band (dB) | system impairment compensation (dB) | maximum hubs distance (km) | NFD provided by 14MHz Guard Band (dB) | system impairment compensation (dB) | maximum hubs distance (km) |
|---|---|---|---|---|---|---|---|
| **Victim** | **Interfer** | | | | | | |
| **4Mb/s** | **4Mb/s** | >66 | >45 | n. a | >66 | >45 | n. a |
| | **8Mb/s** | 55 | 34 | n. a | >66 | >45 | n. a |
| | **16Mb/s** | 44 | 23 | n. a | 61 | 40 | n. a |
| | **34Mb/s** | **30** | **9** | **0,112** | **40** | **19** | **0,355** |
| **8Mb/s** | **4Mb/s** | 69 | 48 | n. a. | >69 | >48 | n. a |
| | **8Mb/s** | 57 | 36 | n. a | >69 | >48 | n. a |
| | **16Mb/s** | 45 | 24 | n. a | 58 | 37 | n. a |
| | **34Mb/s** | **32** | **11** | **0,141** | **42** | **21** | **0,447** |
| **16Mb/s** | **4Mb/s** | 61 | 40 | n. a | >66 | >45 | n. a |
| | **8Mb/s** | 54 | 33 | n. a | 65 | 44 | n. a |
| | **16Mb/s** | 43 | 22 | 0,501 | 57 | 36 | n. a |
| | **34Mb/s** | 32 | 11 | 0,141 | 41 | 20 | 0,398 |
| **34Mb/s** | **4Mb/s** | 51 | 30 | n. a | 65 | 44 | n. a |
| | **8Mb/s** | 54 | 33 | n. a | 66 | 45 | n. a |
| | **16Mb/s** | 40 | 19 | 0,355 | 57 | 36 | n. a |
| | **34Mb/s** | **32** | **11** | **0,141** | **40** | **19** | **0,355** |

**Table 9**

NOTE 1: these tables correspond to a worst case analysis (at least for what concerns co-siting but also, with some exceptions, the near co-siting). This means that no allowance for ISOP has been taken into account, as it is not needed.

NOTE 2: a 500 m maximum rain correlation distance has been assumed; in the table above, higher distances are expressed as n.a.

#### *3.4.3.2 The co-ordinated cell planning*

A different way of increasing the spectrum efficiency, utilising the guard (or better say) edge band, is by mean of a co-ordinated cell planning. The figure below gives an example of how a simple agreement about the particular frequencies and/or polarisation assigned, bye the operators, to the different sectors, during the cell planning phase, can totally solve the interference problems.

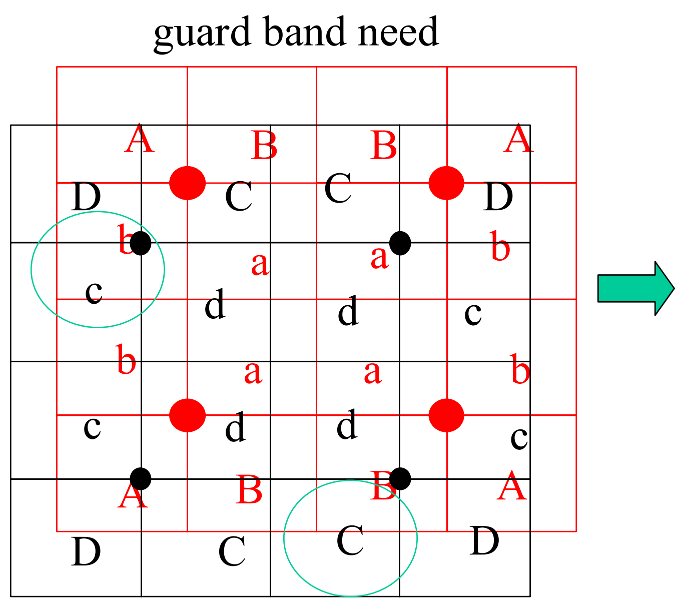



**Figure 19a**

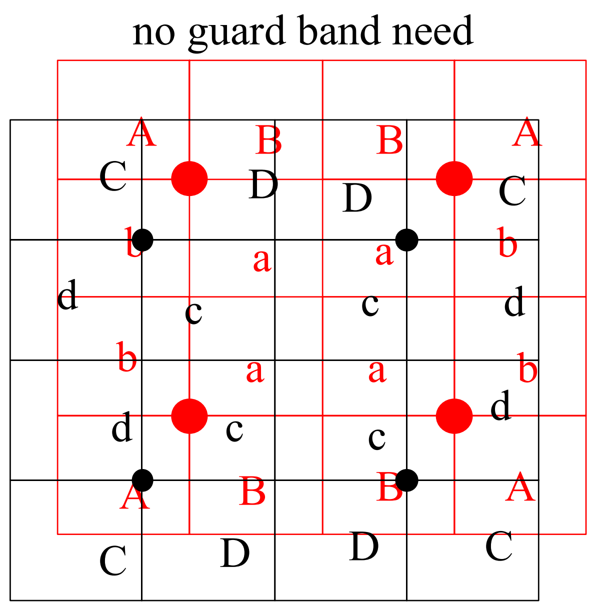



**Figure 19b**

The Figure 19 shows an example of relative cell planning deployment where two neighbouring operators are using two frequencies (A, B and C, D) and two polarisations (a, b and c, d).

The Figure 19a shows interference problems in two sectors (the ones outlined with the green circles) due to a careless (uncoordinated) use of edge frequencies with same polarisation. The Figure 19b shows instead how it would be enough to swap C/c with D/d, in order to solve all the interference problems.

Operators could perhaps agree in advance a division in sectors of the operating area (e.g. town suburbs) and agree a careful use of the edge frequency/polarisation with no need of exchanging actual and detailed information about their own system/coverage deployment and business case.

## 4 ”Adjacent area - same frequency block” interference scenario

This section evaluates the required separation distance between two cells using the same frequency.

### 4.1 The methodologies used

A number of methods have been alternatively used to assess the severity of interference. These are:

- Interference Area (IA), used for the terminal to hub (uplink) scenario
- Interference Scenario Occurrence Probability (ISOP), used for the terminal to hub (uplink) scenario
- Monte Carlo (MC), used for the terminal to terminal scenario
- Worst Case (WC), used for the hub to hub and the hub to terminal (downlink) scenario.

### 4.2 The hub to terminal (downlink) analysis

The hub to terminal and terminal to hub interference scenario is verified in case of FDD, TDD and mixed TDD/FDD systems deployments.

We analyse here the interference scenario where two operators utilise the same frequency band in neighbouring areas, as shown in figure 20.

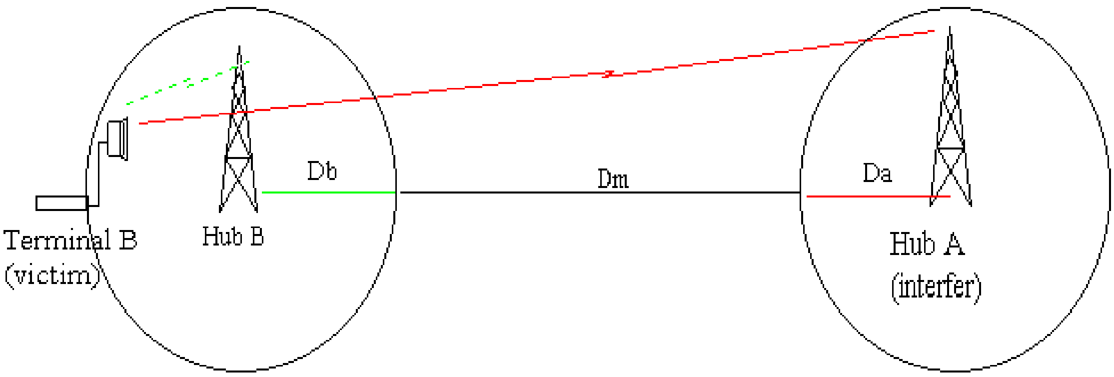



**Figure 20**

The coverage ranges Da and Db are evaluated in table 10, for different system capacities and rain zones (as described in the annex 2).

| ***ITU rain zone:*** | **E** | **K** | **L** |
|---|---|---|---|
| 4Mb/s | 8 | 4.8 | 3.6 |
| 8Mb/s | 7.2 | 4.4 | 3.3 |
| 16Mb/s | 6.5 | 4.0 | 3.0 |
| 34Mb/s | 5.7 | 3.6 | 2.8 |

**Table 10: Coverage range (km) Vs system capacity and rain zones**

The minimum distance Dm between the victim hub B and the interfering terminal A can be evaluated as following, when considering as target the C/I figure (21 dB) which provides 1 dB degradation at 10E-6:

$$-20\text{LOG } Db/(Dm + 2*Db + Da) + (Dm + Db + Da)*Atm = 21 \text{ dB} \qquad (4)$$

where Atm is the atmospheric absorption.

Finally from (4) the minimum distances Dm are evaluated for different system capacities and ITU rain zones and shown in the following table 11:

| PMP Vs PMP compatibility | | **Minimum distance Dm (Km)** | | |
|---|---|---|---|---|
| ***Victim*** | ***Interferer*** | **E zone** | **K zone** | **L zone** |
| 4Mb/s (3.5MHz) | 4Mb/s (3.5MHz) | 16,8 | 15,1 | 13,6 |
| | 8Mb/s (7MHz) | 17,4 | 15,6 | 14,0 |
| | 16Mb/s (14MHz) | 18,2 | 16,0 | 14,3 |
| | 34Mb/s (28MHz) | 19,0 | 16,3 | 14,4 |
| 8Mb/s (7MHz) | 8Mb/s (7MHz) | 16,7 | 14,8 | 13,1 |
| | 16Mb/s (14MHz) | 17,4 | 15,2 | 13,4 |
| | 34Mb/s (28MHz) | 18,0 | 15,5 | 13,6 |
| 16Mb/s (14MHz) | 16Mb/s (14MHz) | 16,4 | 14,2 | 12,5 |
| | 34Mb/s (28MHz) | 17,1 | 14,6 | 12,7 |
| 34Mb/s (28MHz) | 34Mb/s (28MHz) | 16,0 | 13,7 | 12,1 |

**Table 11: Minimum distance Dm for the downlink scenario**

We notice that the minimum distance for safe uncoordinated deployments is 19km, related to a 4Mb/s victim system in the E zone.

### 4.3 The terminal to hub (uplink) analysis

The hub to terminal and terminal to hub interference scenario occurs for FDD, TDD and mixed TDD/FDD systems deployments.

We analyse the uplink interference scenario shown in figure 21.

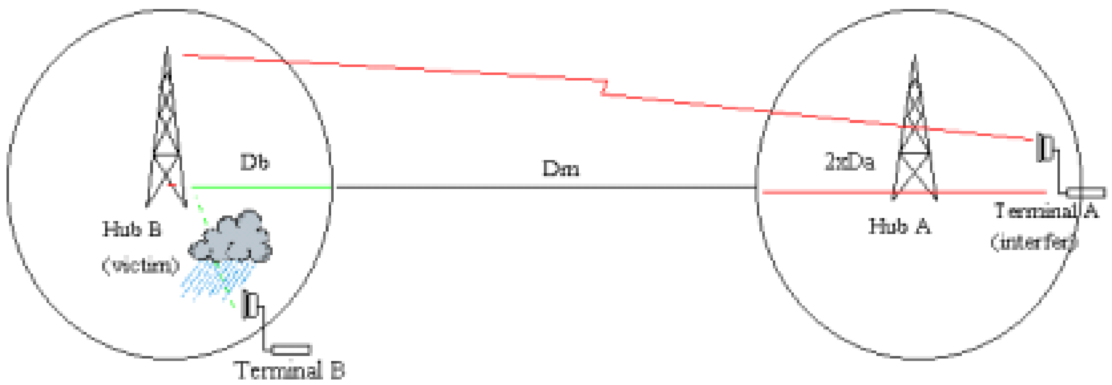



**Figure 21**

The coverage ranges Da and Db are evaluated in table 10, for different system capacities and rain zones.

In this scenario a rain un-correlated attenuation is possible and needs to be considered.

The minimum distance Dm between the victim hub B and the interfering terminal A can be evaluated, in accordance to the system parameters shown in the annex 2, as follows :

C_th-Pout+ATPC-Gn-Gt+92.4 dB+20LOG (F)++20LOG (Dm + Db + 2*Da) + (Dm + Db + 2*Da)*Atm = 21 dB (5)

where Atm is the atmospheric absorption.

ATPC is the power control margin, equals to 15 dB
F is the frequency of operation

Finally from (5) the minimum distances Dm are evaluated for different system capacities and ITU rain zones and shown in the following table 12:

| PMP Vs PMP compatibility | | **Minimum distance Dm (Km)** | | |
|---|---|---|---|---|
| ***Victim*** | ***Interferer*** | **E zone** | **K zone** | **L zone** |
| 4Mb/s (3.5MHz) | 4Mb/s (3.5MHz) | 37,0 | 46,0 | 50,0 |
| | 8Mb/s (7MHz) | 38,0 | 47,0 | 51,0 |
| | 16Mb/s (14MHz) | 40,0 | 48,0 | 52,0 |
| | 34Mb/s (28MHz) | 42,0 | 49,0 | 53,0 |
| 8Mb/s (7MHz) | 8Mb/s (7MHz) | 32,0 | 39,0 | 42,0 |
| | 16Mb/s (14MHz) | 33,0 | 40,0 | 43,0 |
| | 34Mb/s (28MHz) | 35,0 | 41,0 | 44,0 |
| 16Mb/s (14MHz) | 16Mb/s (14MHz) | 25,0 | 33,0 | 35,0 |
| | 34Mb/s (28MHz) | 27,0 | 34,0 | 36,0 |
| 34Mb/s (28MHz) | 34Mb/s (28MHz) | 20,0 | 28,0 | 29 |

**Table 12: Minimum distance Dm for the uplink scenario**

We notice that the minimum distance for safe uncoordinated deployments is 53km, related to a 4Mb/s victim system in the L zone..

### *4.3.1 The ISOP estimation*

This section analyses the interference occurrence probability for the case that the minimum distance between the FWA cells is planned in accordance to the one suggested in section 5.2 (downlink case) rather than to one suggested in section 5.3 (uplink case). Indeed the downlink scenario is deterministic but the uplink one occurs only when several conditions are jointly realised.

The rain attenuation can be considered as uncorrelated only when the interfering terminal is transmitting simultaneously with one of the useful terminals being inside the rain cell.
The Figure 22 shows the reference model for the probability estimation.

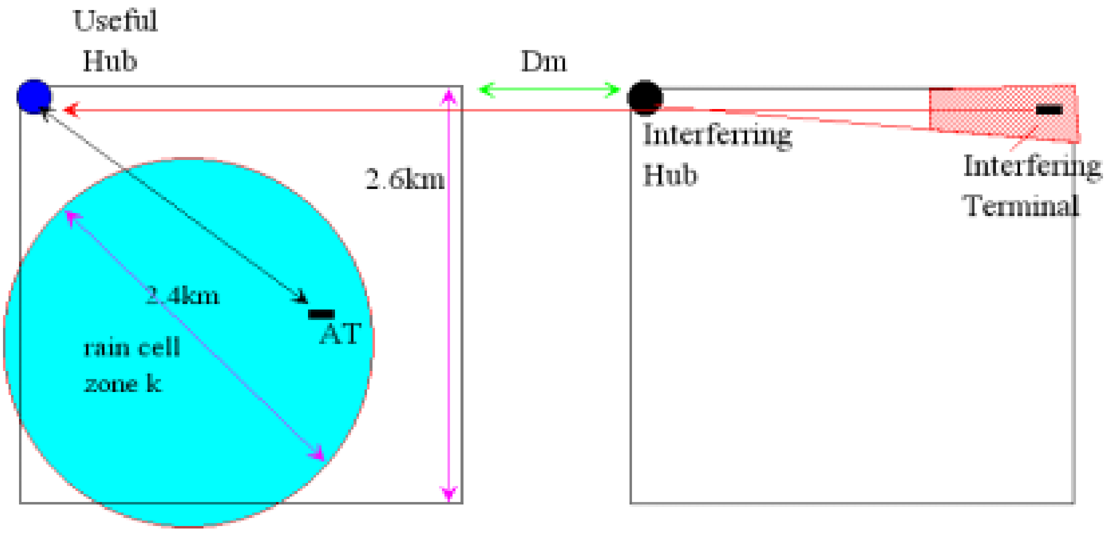



**Figure 22**

According to the above model the interference scenario occurrence probability can be evaluated as follows:

$$ISOP\ (\%) = (1-(1-P_{ant})\hat{}N_t) \times P_{traf} \times P_{area} \times P_{ch}$$

where:
$P_{ant}$ is the probability of having the victim and interfering antennas aligned that means the probability of having a terminal inside the Interference Area. In practice $P_{ant}$ is the ratio between IA and the whole sector area (Area_sect). The IA can be approximated as a triangle having the height equal to the sector size and the apex angle equal to half of the 3 dB lobewidth (4°/2) of the interfering terminal antenna. It is worth noting that, in the Interfering sector, the terminals closer to the hub, cause an interference level which is smaller as the ATPC can increase his margin up to around 45 dB (30 dB more than the one at the corner). This would probably cause to reduce the interference area down to a factor around 1/3. The table below shows the values of the interference levels, at the hub in the victim sector, when the terminals in the interfering one are at different distances. Dm is assumed as 20km. The nominal Rx level, in clear sky condition, has been assumed as kept, by ATPC, at – 70 dBm. The $P_{out}$ (RF output power) values shown are the ones emitted by the interfering terminal. The C/I values shown are the worst case ones when the useful terminal is near to the useful sector corner. See also the simulation results shown in Figure 24.

| D(km) | Pout(dBm) | Rx_hub_useful (dBm) | Rx_hub_victim (dBm) | C/I_th (dB) |
|---|---|---|---|---|
| 2,6 | 6,5 | -70,0 | -94,3 | 17,3 |
| 1,8 | 3,2 | -70,0 | -97,3 | 20,3 |
| 1 | -2,1 | -70,0 | -102,3 | 25,3 |
| 0,2 | -16,2 | -70,0 | -116,0 | 39,0 |

**Table 13**

The table 13 shows that the portion of the interference area near to the sector side corner is the only one causing light interference problems.
Hence $P_{ant}$ can be approximated as (1/3)*(2°/90°) which is the ratio in radians between the interference area and the sector area.

1-(1-Pant)^$N_t$ is the probability that at least one interfering terminal falls into the interference area when the terminal stations (TSs) per sector per operators are $N_t$,

$P_{traf}$ is the probability related to the traffic behaviour of both TDMA and FDMA systems. Indeed as TDMA systems don't perform in the uplink direction continuous transmission, the interference occurrence is tied to the probability of simultaneous transmission of both the interfering terminal, being located in the interference area, and the useful terminal, being located in the rain area (see Figure 23-1,-2 and -3 for better understanding). In the other hand FDMA systems perform continuous transmission but subdividing the available channel in several portions and accordingly subdividing the available RF power.
In both cases either the interference probability or the interference level are strongly mitigated by the system traffic behaviour by a factor which is tied to the number of terminals in the interfering sector. Hence $P_{traf}$ can be approximated, assuming a uniformly distributed traffic, as $1/N_t$, where $N_t$ is the number of terminals into the interfering sector.

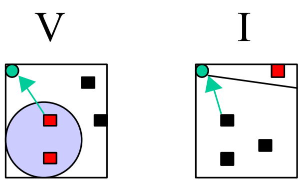



Figure 23.1

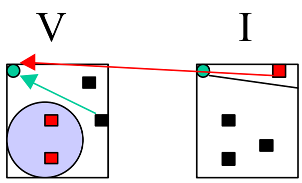



Figure 23.2

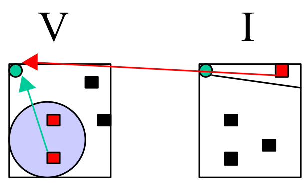



Figure 23.3

The Fig 23.1 and .2 show no interference occurrence
The Fig 23.3 shows interference occurrence, which is conditioned, to combined simultaneous events

V: victim sector; I: interfering sector

The Figure 24 shows that the uplink C/I level is time variant and traffic dependent. It has been statistically evaluated, based on the following assumptions:

- Terminals (they are ranging from 15 to 120) location randomly distributed
- Terminals traffic uniformly distributed
- Transmitting terminals, at given instant and at a given sector, are randomly chosen
- ATPC is available

The simulation shows 8000 events (or TDMA time slots) in which the C/I level never goes below 25 dB (well above the target).

$P_{area}$ is the probability that the useful terminals lie in the rain area of the sector, defined as "Area_rain".

$P_{ch}$ is related to the mutual cell planning deployment carried out by the neighbouring operators. It is the probability that one interfering hub uses a channel, which is adjacent and co-polar to the victim channel. Pch depends on the number of available channels per operators and on the relative cell planning deployments. For square sector deployments, $P_{ch}$ equals to [2/(Reuse_fact*$N_{ch}$)], where rf is the sector frequency reuse factor and $N_{ch}$ is the number of different carriers, with single or double polarization (here defined as available channels) used in the cell planning. See annex 3 for further explanations.

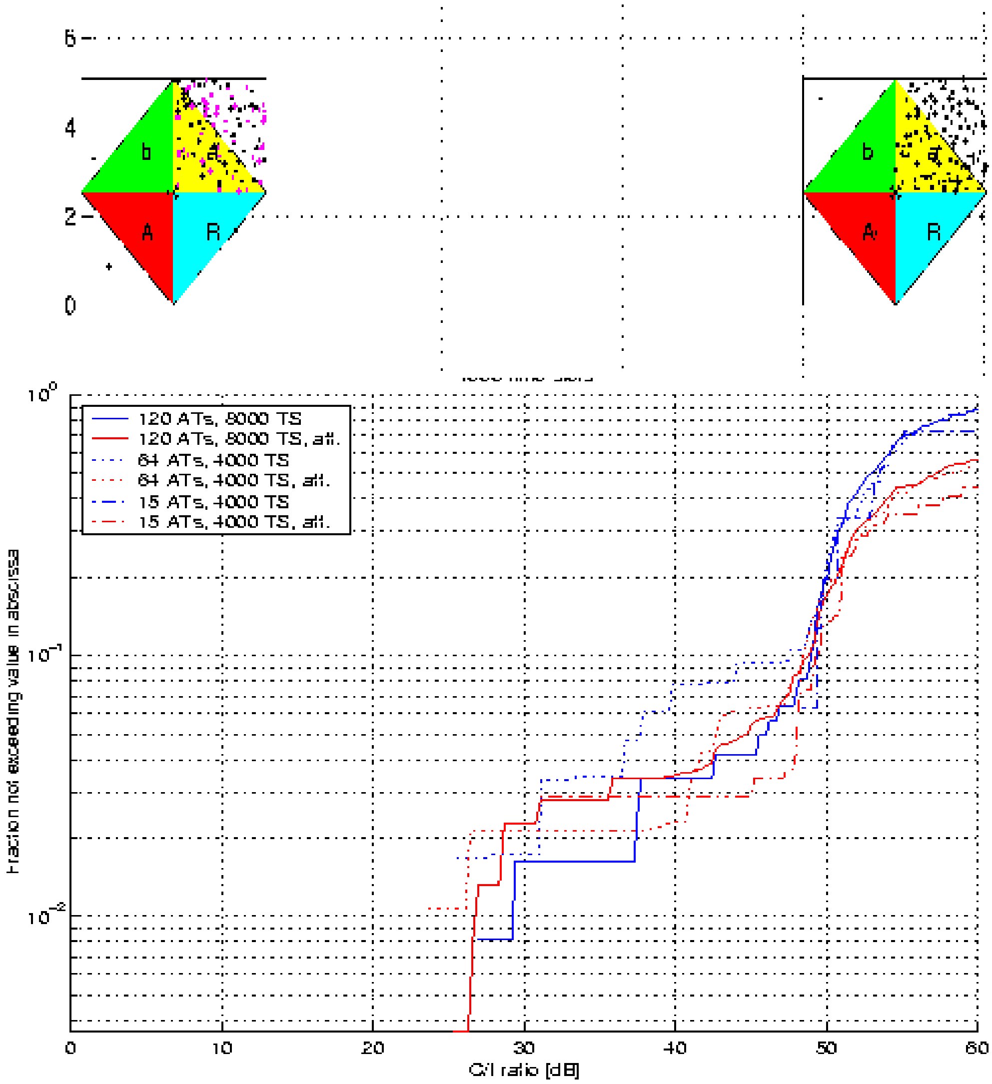



**Figure 24**

From what above we can evaluate that:

$$ISOP(\%) = \left[1-\left(1-P_{ant}\right)^{Nt}\right]*\frac{1}{Nt}*\frac{area\_rain}{area\_sect}*\frac{2}{Reuse\_fact*Nch} = \left[1-\left(1-\frac{4}{90}*\frac{1}{3}\right)^{Nt}\right]*\frac{1}{Nt}*\frac{\pi*1.2^2}{2.6^2}*\frac{2}{1*4}$$

The Figure 25 shows the ISOP value against the number of terminal in the interfering sector, the number of available channels per operator and the frequency sector reuse factor.

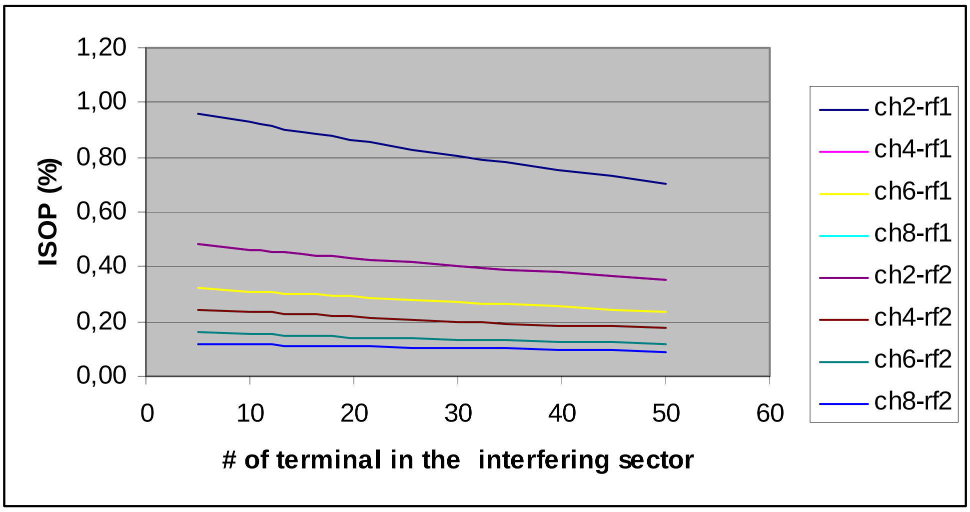



**Figure 25**

Note that the ISOP value is never above 1%.

#### *4.3.2 Interference area estimation by Monte Carlo methods*

This section describes how Monte Carlo methods can be used to estimate the area of the interfering co-channel cell in which TSs may cause interference into the victim cell, and hence the probability of such interference occurring. The method is based on similar principles to the method described in Section 4.2.2, so only brief details are given here.

##### *4.3.2.1 Geometry and method*

Figure 26 shows the geometry of the situation.

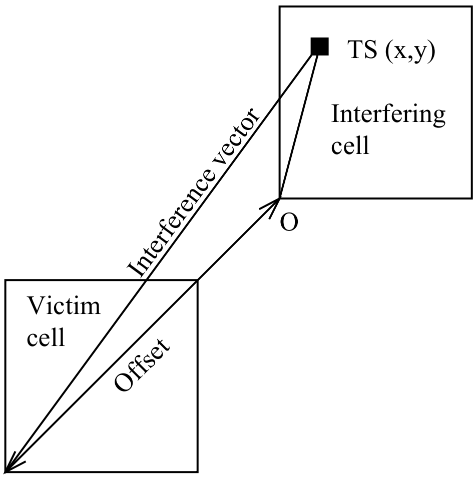



**Figure 26: MC Interference geometry for co-channel uplink**

A terminal TS in the interfering sector has coordinates (x,y) relative to the CS which is assumed located at the origin O, and points directly at O. The victim sector is located in the worst case so that its diagonal passes through O, with its TS located at an offset from the CS defining the interfering sector. The interference vector shown is found, and knowing its length and angle the interference level at V can be found given the RPE pattern of the TS antenna. In doing this the TS transmit power is scaled according to its distance from its serving CS to simulate ATPC. The proportion of the area of the interfering cell for which the interference is above a value which is 21 dB below the system threshold is required. This proportion is the Interference Area IA.

A Monte Carlo method very similar to that used for the down-link simulations of Section 4.2.2 is used, simply modified to not use an NFD and to take account of the atmospheric attenuation.

It should be noted that this method is worst case in the sense that it assumes that any TS in the interference area is actually transmitting. In practice of course, this will not be the case. Whether or not a TS is actually transmitting will depend on the access protocol (TDMA, FDMA etc.), and the traffic level and traffic type (ABR, CBR, etc.) in both victim and interfering cells.

Given the value of IA an ISOP can be computed using the previous formula:

$$\text{ISOP} \quad = \quad 0.2446\,(1 - [1 - \text{IA}]^{Nt}).$$

*4.3.2.2 Results*

Results are computed for two of the antenna types of Section 4.2.2, which represent extreme cases. One is the ETSI TS1 antenna, Type A; the other is the TM 04069 antenna, Type C. The simulation parameters are as follows.

| | |
|---|---|
| Interfering cell size | 3.6 km |
| Maximum TS Tx power | 24 dBm |
| Cell edge ATPC back-off | 15 dB |
| Maximum TS EIRP | 43 dBm |
| Atmospheric attenuation | according to ITU R.676-3 annex 2 |
| Victim CS antenna gain | 19 dB |
| System threshold | -77 dBm (28 MHz TDMA system) |

Figure 27 is a plot of the IA and ISOP values for antenna Type A.

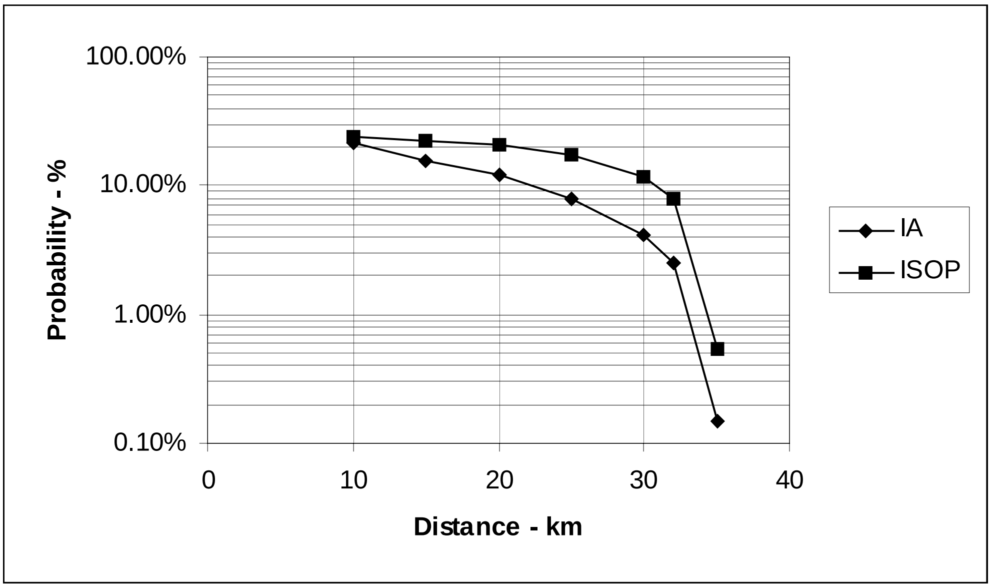



**Figure 27: IA and ISOP, co-channel, Antenna Type A**

Figure 28 shows the points within the IA for a distance of 20 km, plotted against their coordinates in the sector. The effect of the power control in truncating the IA close to the CS can be seen clearly.

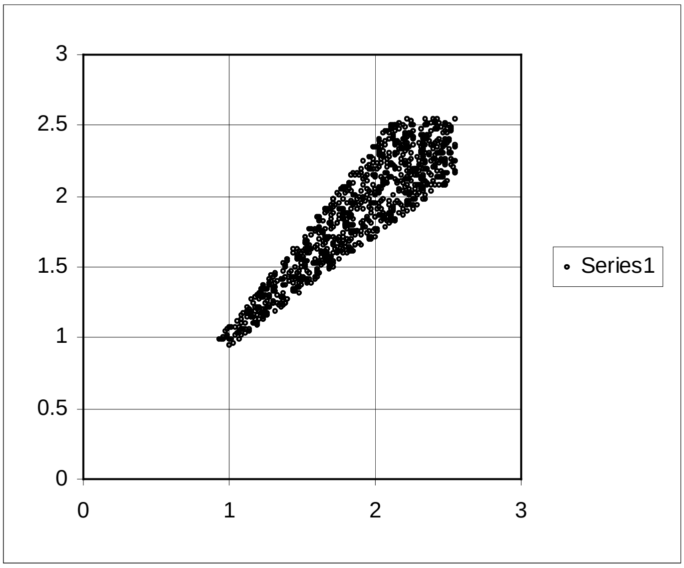



**Figure 28: TS locations within IA, distance = 20 km**

Figure 29 plots the ISOP and IA for the Type C antenna. Because the transmit power is adjusted for the same maximum EIRP, the range at which IA is zero is the same as the previous case. However, it can generally be seen that the curves lie below those of the lower performance antenna.

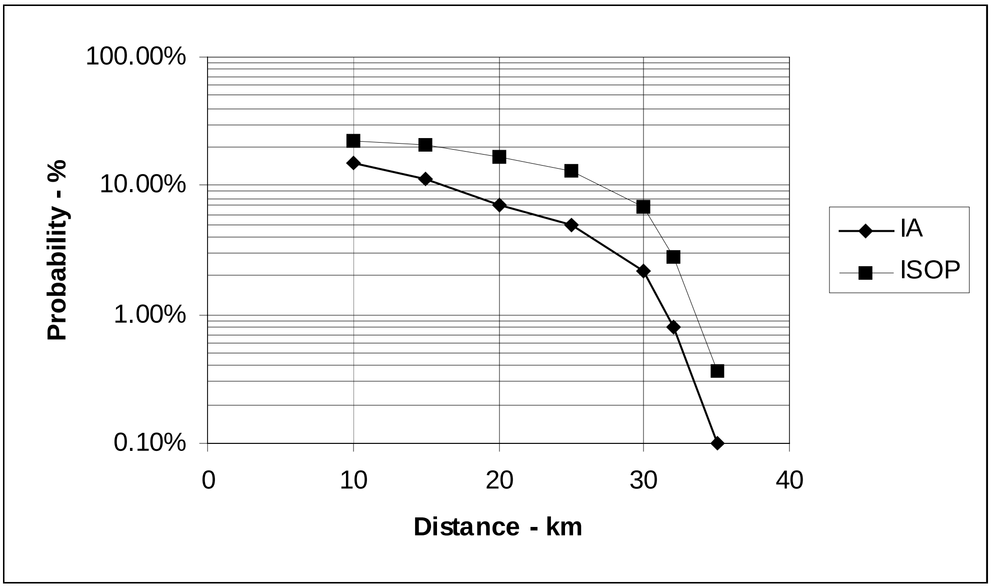



**Figure 29: IA and ISOP, co-channel, Antenna Type C**

*4.3.2.3 Discussion*

The results above show that the interference area can readily be estimated using a Monte Carlo method, which allows the comparison of different antenna patterns.

It is apparent that the IA is a sensitive function of cell spacing. The ISOP which is derived from IA shows that quite high probabilities of interference result for spacings which are not much less than the spacing value computed on a worst-case basis.

ISOP is quite an appropriate measure of interference for the co-channel case, since it is the probability that "*at least one terminal is located in the interference area*". Interference problems could arise even if the operator of the interfering system locates one TS in the wrong place, and it may be difficult or impossible to co-ordinate between the operators. It can be seen that at distances, which are of the order of half the worst-case distance, for both the antenna types considered, ISOPs of the order of 20% result.

The IA method presented here makes the worst case assumption that every TS in the interference area transmits at a time when it will interfere with a transmission in the victim cell. Section 5.3.1, presenting the ISOP method for the co-channel up-link case, has given a Monte-Carlo analysis of traffic effects.

### 4.4 The terminal to terminal MC interference analysis

The hub to hub interference scenario is verified in case of TDD and mixed TDD/FDD systems deployments. The FDD systems are not affected.

Section 4.4 described the general method of Monte-Carlo analysis. This section describes the results for adjacent area, same frequency deployment.

Figure 30 shows the interference distribution functions for a range of normalised overlaps corresponding to cell centre distances which are interesting in the uplink co-channel interference case. The maximum probability of interference is constant at about 0.5%; but the C/I ratio is 30 dB or better for most cases. This figure will again be either unaffected or increased by rain fading. Note that a normalized "overlap" of 10 corresponds to a distance of 35 km for typical 3.5 km sector maximum radius. The actual CS-CS spacing will then be 8 x 3.5 km = 28 km; and the cell boundary spacing will be 21 km. Obviously lower spacings could also be used without significantly increasing the interference probability.

This calculation has also ignored the effect of atmospheric attenuation. In the 24.5 – 29.5 GHz band this ranges around 0.2 – 0.1 dB/km in Europe. Its main effect is on the longer, interfering path, where it could be expected to increase the attenuation, and consequently the C/I ratio, by around 4 dB maximum.

The results show that the TS – TS interference will not be the limiting factor for this interference scenario.

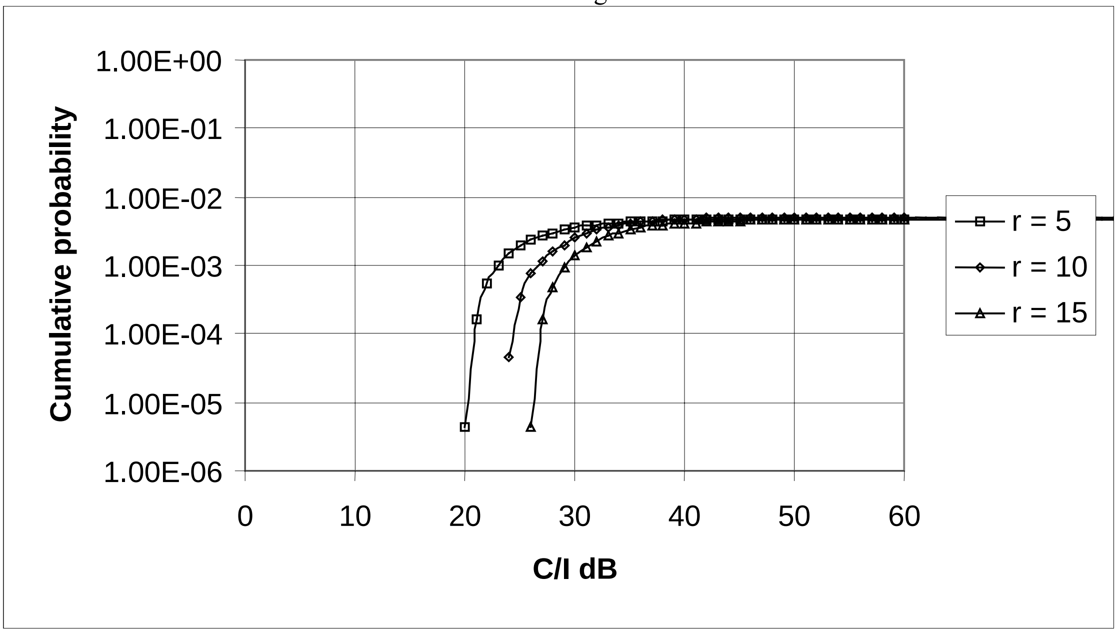



**Figure 30: C/I distribution for same frequency adjacent area case**

## 4.5 The hub to hub interference analysis

The hub to hub interference scenario is verified in case of TDD and mixed TDD/FDD systems deployments. The FDD systems are not affected.
We analyse the hub to hub interference scenario shown in figure 31.

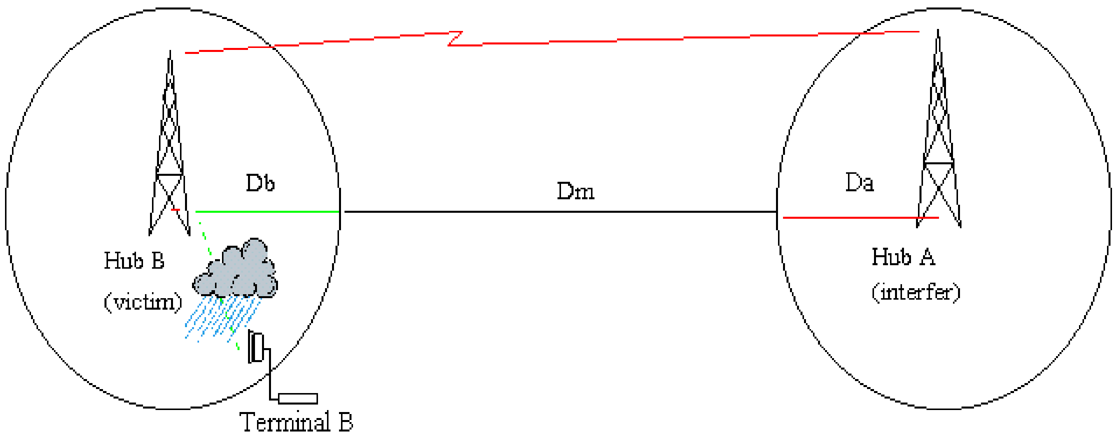



**Figure 31**

The coverage ranges Da and Db are evaluated in table 10, for different system capacities and rain zones.

In this scenario a rain attenuation can be un-correlated and this needs to be considered.

The minimum distance Dm between the victim hub B and the interfering terminal A can be evaluated, in accordance with the system parameters shown in the annex 2, as follows, when considering as target the C/I figure (21 dB) which causes 1 dB degradation at 10E-6 BER:

$$Cth-Pout-Gt-Gn+92.4\ dB+20LOGF+20LOG(Dm + Db + Da) + (Dm + Db + Da)*Atm = 21\ dB \qquad (6)$$

where Atm is the atmospheric absorption,.
F is the frequency of operation.

Finally from (6) the minimum distances Dm are evaluated for different system capacities and ITU rain zones and shown in the following table 14:

| PMP Vs PMP compatibility | | **Minimum distance Dm (Km)** | | |
|---|---|---|---|---|
| ***Victim*** | ***Interferer*** | **E zone** | **K zone** | **L zone** |
| 4Mb/s (3.5MHz) | 4Mb/s (3.5MHz) | 44,0 | 51,0 | 53,0 |
| | 8Mb/s (7MHz) | 46,0 | 52,0 | 54,0 |
| | 16Mb/s (14MHz) | 47,0 | 53,0 | 55,0 |
| | 34Mb/s (28MHz) | 48,0 | 54,0 | 56,0 |
| 8Mb/s (7MHz) | 8Mb/s (7MHz) | 38,0 | 43,0 | 45,0 |
| | 16Mb/s (14MHz) | 39,0 | 44,0 | 46,0 |
| | 34Mb/s (28MHz) | 40,0 | 45,0 | 47,0 |
| 16Mb/s (14MHz) | 16Mb/s (14MHz) | 32,0 | 36,0 | 38,0 |
| | 34Mb/s (28MHz) | 33,0 | 37,0 | 39,0 |
| 34Mb/s (28MHz) | 34Mb/s (28MHz) | 26,0 | 30,0 | 32 |

**Table 14 : Minimum distance Dm for TDD or TDD/FDD systems (hub-to-hub scenario)**

We notice that the minimum distance for safe uncoordinated deployments is 56km, related to a 4Mb/s victim system in the L zone.

### 4.6 Conclusions on guard distances

We can summarise, in table 15, the results relevant to the worst “minimum distances Dm” evaluated in the section 5.1, 5.2 and 5.3 and the ISOP and IA evaluated in section 5.3.1 and 5.3.2:

| **Interference scenario** | | **FDD (km)** | **TDD (km)** | **ISOP(%)** |
|---|---|---|---|---|
| Hub to terminal | Downlink | 19 | 19 | 100 |
| | Uplink | 53 | 53 | <1 |
| Terminal to terminal | Downlink | - | 19 | 100 |
| | Uplink | - | 19 | 100 |
| Hub to hub | Downlink | - | 56 | <22 |
| | Uplink | - | 56 | <22 |

**Table 15 : Worst minimum distance (km) and relevant ISOP (%)**

We can conclude what following:

- The result of the downlink (hub to terminal) scenario is a guard distance estimation of about 20 km.
- The result of the uplink (terminal to hub) scenario is a guard distance estimation of about 55 km. The different result in respect to the above downlink scenario is due to the possibility of no rain attenuation correlation. This guard distance can be reasonably reduced to 40 km, taking into consideration the earth bulge (obstruction effect inside the 1st Fresnel ellipsoid due to the earth curvature) at typical antenna tower heights (e.g.30 m).
- It is worth noting that the occurrence probability of the rain uncorrelation interference scenario in the uplink case is quite low (according to the ISOP method). This can suggest the alternative adoption of 20 km as minimum guard distance.
- For the hub to hub interference scenario, a guard distance of 55km is suggested, according to the high probability occurrence of the rain uncorrelation scenario in the uplink direction. This guard distance can be reasonably reduced to 40km, taking into consideration the earth bulge (obstruction effect inside the 1st Fresnel ellipsoid due to the earth curvature) at typical antenna tower heights (e.g.30 m)

## 5 FINAL CONSIDERATIONS

From the analyses presented, one can further outline the following:

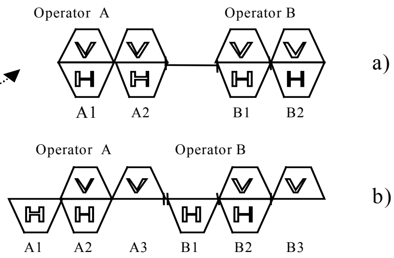
- In case of planned deployment FDD systems require 1x28MHz guard band, TDD or mixed TDD/FDD systems require either 2x28MHz guard band or 1x28MHz guard band plus a minimum co-ordination distance of at least 500 m.

- Co-siting/ near co-siting and/or cell planning co-ordination permits the greatest efficiency and the spectrum can be used more efficiently under this configuration. This requires a co-operation between the operators and may not be always achievable;

- Whenever such co-operation might not be ensured, some guard band is necessary between two operators using adjacent blocks of spectrum;

- The guard band may consist of one or more unused slots of frequency, or of slots used only with one polarisation, adjacent to slots used on the opposite polarisation;

| ISOP (%) | Minimum distance | Guard Band requirements |
|---|---|---|
| **<1** | 700mt | 1ch |




XPD gives more flexibility on spectrum blocks allocation
when guard bands are inside the block assigned to an Operator

**Figure 32**

- It would be very useful, in order to use the spectrum more efficiently especially in hot spots, that the operators co-operate; in this case the guard bands proposed may be reduced even a certain time after the original deployment and be considered just as ”edge” bands. As the analysis in section 4.4.3 shows, the guard bands may even be eliminated in several cases and the originally unused spectrum be employed by the two operators.

- In case of unplanned/co-operative deployment (where the guard bands are inside the contiguously assigned blocks) the spectrum allocation shown in Figure 32b) can provide a more efficient way of using the “edge” band, since it allows to equally splitting the guard spectrum between the neighbouring operators. The unused polarisation can be fully or partially used, if/when a degree of co-operation, i.e. site sharing and/or co-ordinated cell planning, is agreed by the operators. This could be particularly important for TDMA systems using channels of bandwidth equal to an entire slot, while for FDMA systems, using subcarriers, it is indifferent to use the XPD separation or to sub-divide the unused slot in Figure 32a).

- The analysis of pattern deployment revealed that a frequency reuse factor of two permits to realise the higher code rate efficiency while a reuse factor of one requires high complexity (e.g. in terms of error correction capability).

Finally, the administrators are invited to refer to the flow-chart in section 2.1 in order to understand the major choices to be made when establishing the strategy for the allocation of spectrum.

**Annex 1**

## ANNEX 1: NFD (NET FILTER DISCRIMINATION) TABLES

| Victim<br>Interferer<br>dF(MHz) | 4Mb/s<br>4Mb/s | 4Mb/s<br>8Mb/s | 4Mb/s<br>16Mb/s | 4Mb/s<br>34Mb/s | 8Mb/s<br>4Mb/s | 8Mb/s<br>8Mb/s | 8Mb/s<br>16Mb/s | 8Mb/s<br>34Mb/s |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1,75 | 2 | 1 | 0 | 0 | 0 | 1 | 1 | 0 |
| 3,5 | 20 | 8 | 3 | 1 | 1 | 2 | 2 | 1 |
| 5,25 | 37 | 21 | 8 | 2 | 22 | 12 | 5 | 2 |
| 7 | 56 | 33 | 14 | 3 | 43 | 23 | 10 | 3 |
| 8,75 | 66 | 45 | 21 | 5 | 56 | 33 | 16 | 5 |
| 10,5 | 74 | 51 | 28 | 8 | 64 | 44 | 23 | 7 |
| 12,25 | 81 | 55 | 34 | 11 | 69 | 51 | 29 | 10 |
| 14 | 84 | 61 | 39 | 15 | 74 | 57 | 35 | 13 |
| 15,75 | | 66 | 44 | 18 | 79 | 62 | 40 | 17 |
| 17,5 | | 73 | 48 | 21 | 82 | 66 | 45 | 20 |
| 19,25 | | 79 | 52 | 24 | | 69 | 49 | 23 |
| 21 | | 83 | 55 | 27 | | 73 | 53 | 26 |
| 22,75 | | | 58 | 30 | | 76 | 56 | 29 |
| 24,5 | | | 61 | 33 | | 79 | 58 | 32 |
| 26,25 | | | 64 | 36 | | 81 | 61 | 35 |
| 28 | | | 67 | 38 | | | 63 | 37 |
| 29,75 | | | 70 | 40 | | | 65 | 40 |
| 31,5 | | | 73 | 42 | | | 67 | 42 |
| 33,25 | | | 76 | 44 | | | 69 | 44 |
| 35 | | | 80 | 46 | | | 71 | 46 |
| 36,75 | | | 83 | 48 | | | 73 | 48 |
| 38,5 | | | | 50 | | | 75 | 50 |
| 40,25 | | | | 52 | | | 77 | 52 |
| 42 | | | | 54 | | | 80 | 53 |
| 43,75 | | | | 56 | | | | 55 |
| 45,5 | | | | 58 | | | | 57 |
| 47,25 | | | | 60 | | | | 59 |
| 49 | | | | 62 | | | | 60 |
| 50,75 | | | | 64 | | | | 62 |
| 52,5 | | | | 66 | | | | 63 |
| 54,25 | | | | 68 | | | | 64 |
| 56 | | | | 70 | | | | 66 |
| 57,75 | | | | 72 | | | | 67 |
| 59,5 | | | | 74 | | | | 69 |
| 61,25 | | | | 76 | | | | 70 |
| 63 | | | | 77 | | | | 71 |
| 64,75 | | | | 78 | | | | 73 |
| 66,5 | | | | 79 | | | | 74 |
| 68,25 | | | | 80 | | | | 76 |
| 70 | | | | 82 | | | | 77 |
| 71,75 | | | | 83 | | | | 78 |
| 73,5 | | | | | | | | 80 |

| Victim<br>Interferer<br>dF(MHz) | 16Mb/s<br>4Mb/s | 16Mb/s<br>8Mb/s | 16Mb/s<br>16Mb/s | 16Mb/s<br>34Mb/s | 34Mb/s<br>4Mb/s | 34Mb/s<br>8Mb/s | 34Mb/s<br>16Mb/s | 34Mb/s<br>34Mb/s |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1,75 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3,5 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 5,25 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 7 | 0 | 1 | 1 | 2 | 0 | 0 | 0 | 0 |
| 8,75 | 15 | 7 | 3 | 3 | 0 | 0 | 0 | 0 |
| 10,5 | 32 | 15 | 7 | 4 | 0 | 0 | 0 | 1 |
| 12,25 | 50 | 27 | 15 | 5 | 0 | 0 | 0 | 2 |
| 14 | 57 | 39 | 23 | 7 | 0 | 1 | 1 | 3 |
| 15,75 | 61 | 47 | 29 | 9 | 7 | 5 | 5 | 3 |
| 17,5 | 64 | 54 | 34 | 12 | 13 | 11 | 9 | 4 |
| 19,25 | 66 | 59 | 39 | 15 | 26 | 21 | 14 | 5 |
| 21 | 70 | 61 | 43 | 19 | 39 | 33 | 19 | 6 |
| 22,75 | 73 | 63 | 47 | 23 | 51 | 44 | 24 | 10 |
| 24,5 | 76 | 65 | 51 | 26 | 57 | 54 | 30 | 14 |
| 26,25 | 79 | 67 | 54 | 29 | 61 | 59 | 35 | 18 |
| 28 | | 68 | 57 | 32 | 64 | 63 | 40 | 23 |
| 29,75 | | 70 | 60 | 35 | 65 | 65 | 45 | 26 |
| 31,5 | | 72 | 62 | 37 | 66 | 66 | 49 | 28 |
| 33,25 | | 74 | 64 | 39 | 67 | 67 | 53 | 30 |
| 35 | | 76 | 65 | 41 | 69 | 68 | 57 | 32 |
| 36,75 | | 78 | 66 | 43 | 70 | 69 | 60 | 34 |
| 38,5 | | | 68 | 45 | 71 | 70 | 62 | 36 |
| 40,25 | | | 69 | 47 | 72 | 71 | 64 | 38 |
| 42 | | | 70 | 49 | 73 | 72 | 66 | 40 |
| 43,75 | | | 71 | 51 | 74 | 73 | 67 | 42 |
| 45,5 | | | 73 | 53 | | 74 | 68 | 44 |
| 47,25 | | | 74 | 55 | | | 69 | 46 |
| 49 | | | 75 | 56 | | | 70 | 47 |
| 50,75 | | | 77 | 57 | | | 71 | 49 |
| 52,5 | | | | 58 | | | 72 | 51 |
| 54,25 | | | | 59 | | | 73 | 53 |
| 56 | | | | 60 | | | 74 | 54 |
| 57,75 | | | | 61 | | | | 56 |
| 59,5 | | | | 62 | | | | 58 |
| 61,25 | | | | 63 | | | | 60 |
| 63 | | | | 64 | | | | 61 |
| 64,75 | | | | 65 | | | | 62 |
| 66,5 | | | | 66 | | | | 63 |
| 68,25 | | | | 67 | | | | 64 |
| 70 | | | | 68 | | | | 65 |
| 71,75 | | | | 69 | | | | 66 |
| 73,5 | | | | 70 | | | | 67 |
| 75,25 | | | | 71 | | | | 68 |
| 77 | | | | 72 | | | | 69 |
| 78,75 | | | | 73 | | | | 70 |
| 80,5 | | | | 74 | | | | 71 |
| 82,25 | | | | 75 | | | | 72 |
| 84 | | | | 77 | | | | 73 |
| 85,75 | | | | | | | | 74 |

## Annex 2

## ANNEX 2: COVERAGE RANGE AND AVAILABILITY TARGET

The maximum distance (or service radius) between the hub (or Central station) and the TS (or Terminal Station) is related to the availability target parameters (stated by the operator in the range of 99-99.99% of the time) and rain zones. We limit our evaluation for the 99.99% availability target for 10E-6 threshold and the ITU rain zones E, K and L. It is worth noting that the maximum distance or coverage range (equivalent of the is also depending on the system MTBF (Mean Time Between Failure) and on the MTTR (Mean Time To Restore) supported by the operator maintenance organisation.

Assuming an hardware availability of 99.9985%, the effective residual unavailability target due to rain fading is 0.0085% of the time.

The table 1 shows the maximum coverage range, for the horizontal polarisation, in accordance with [1] and by using the system parameters reported in table 2:

| *ITU rain zone:* | E | K | L |
|---|---|---|---|
| 4Mb/s | 8 | 4.8 | 3.6 |
| 8Mb/s | 7.2 | 4.4 | 3.3 |
| 16Mb/s | 6.5 | 4.0 | 3.0 |
| 34Mb/s | 5.7 | 3.6 | 2.8 |

**Table 1: Coverage ranges (km) Vs system capacity and rain zones**

| | |
|---|---|
| Tx power output (Pout): | 24 dBm |
| | |
| *Receiver Threshold at 10E-6 (C_th):* | |
| 4 Mb/s (3.5 MHz channel size): | -86 dBm |
| 8 Mb/s (7 MHz channel size): | -83 dBm |
| **16 MB/S (14 MHZ CHANNEL SIZE):** | -80 dBm |
| 34 Mb/s (28 MHz channel size): | -77 dBm |
| | |
| *Antenna Gain* | |
| Terminal Station – TS (Gt): | 34 dB |
| Central Station – CS (Gn): | 19 dB |
| | |
| | |
| NFD : | see annex 1 |
| | |
| XPD: | 30 dB |
| | |
| Co-channel C/I (C/I_th):<br>(for 1dB degradation at the 10E-6 Threshold) | 21 dB |
| | |

**Table 2: System parameters used for coverage range and guard band evaluation**

The table 3 shows the typical rain cell diameter Dc, evaluated as a function of the rainfall rate R(mm/h), according to ITU-R P.452-8, appendix 3, annex 1.
For the rain zone k: Dc = 3.3xR^-0.08 = 2.4 km.

| *ITU rain zone:* | E | K | L |
|---|---|---|---|
| Rain cell | 2.5 | 2.4 | 2.3 |

**Table 3: Rain cell diameter (km) Vs and rain zones**

[1] - “Propagation data and prediction methods required for the design of terrestrial line-of-sight systems”
– ITU-R Rec. P.530-7

## Annex 3

### ANNEX 3: PROBABILITY OF INTERFERENCE RELATED TO CELL PLANNING DEPLOYMENTS

The probability of interference ($P_3$), related to the cell planning deployments carried out by the neighbouring operators, is the probability that one interfering hub lies in each useful sector and uses a channel, which is adjacent and co-polar to the victim channel. $P_3$ depends on the number of available channels per operators and on the relative maximum coverage deployed by neighbouring systems.
The worst case cell planning deployment (as shown in the figure 1) is here evaluated, based on following assumptions:

- Any sector has an interfering hub due to the possible coverage range impairments of the different systems operated by the neighboring operators. The max achievable coverage range of the system operated by the operator A is half of the one achieved by the system operated by the operator B.
- There are two neighboring operators
- The frequency reuse factor is one

The figure below shows an example of cell planning deployment of three neighboring operators, all having a frequency reuse factor of one. The Figure 1a shows the A and B operators interference situation. The Figure 1b shows that possible alternative combinations have the only useless result to swap the interfered sectors. The operator B, the one in the middle, suffers interference problems in all sectors. See Figure1c.

For square sector deployments, $P_3$ can be shown to be equal to [2/( Reuse_fact*Nch)]*[($d_b/d_a$)^2/4] by considering the different possible cases], where rf is the sector frequency reuse factor and N is the number of different carriers, with single or double polarisation (here defined as available channels) used in the cell planning. The terms $d_b$ and $d_a$ are respectively the max coverage ranges achievable by the systems operated by the neighboring operators. We note that [($d_b/d_a$)^2/4], equals 1 when $d_b = 2*d_a$ as hereby assumed according to the used worst case criterion.

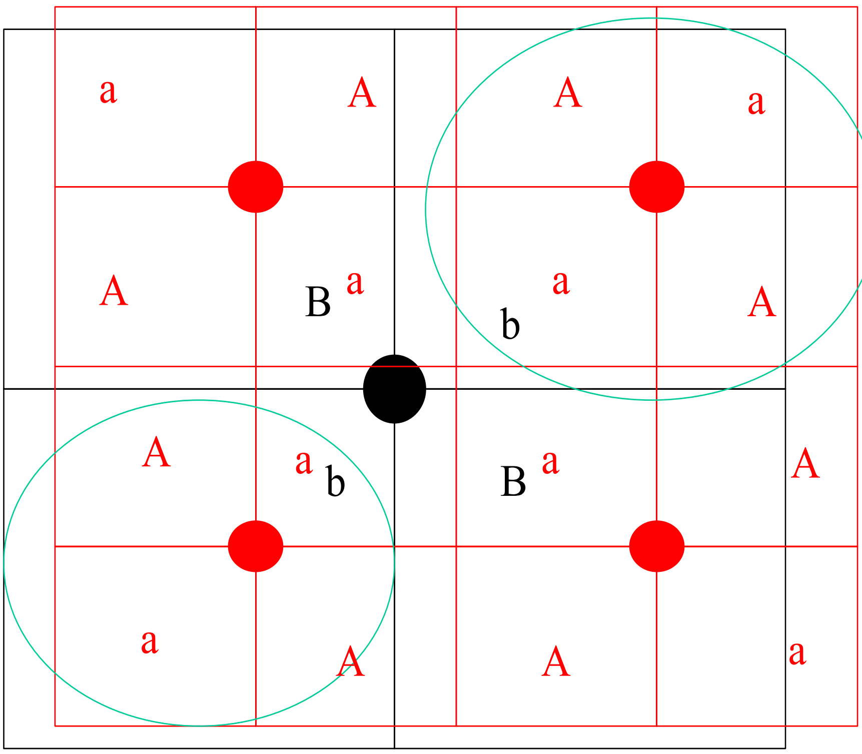



**Figure 1a**

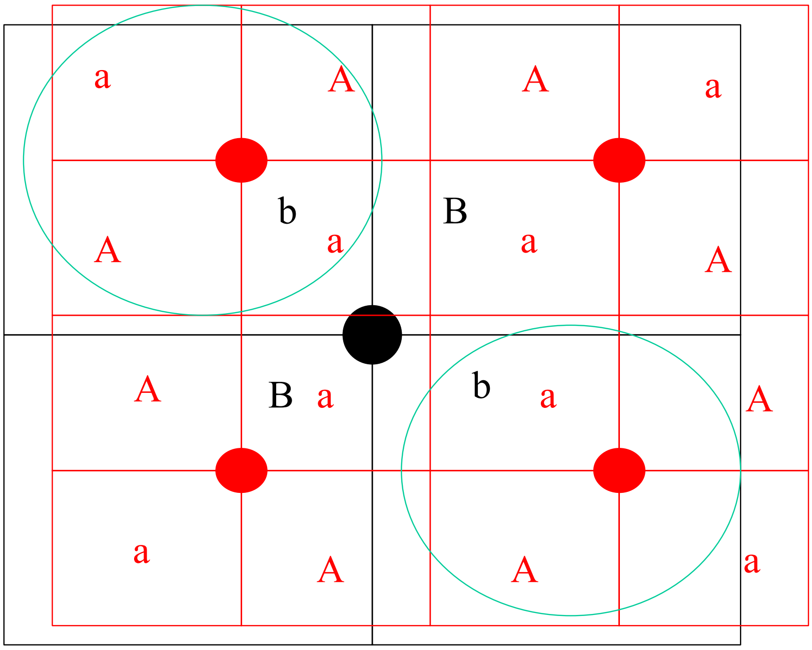



**Figure 1b**

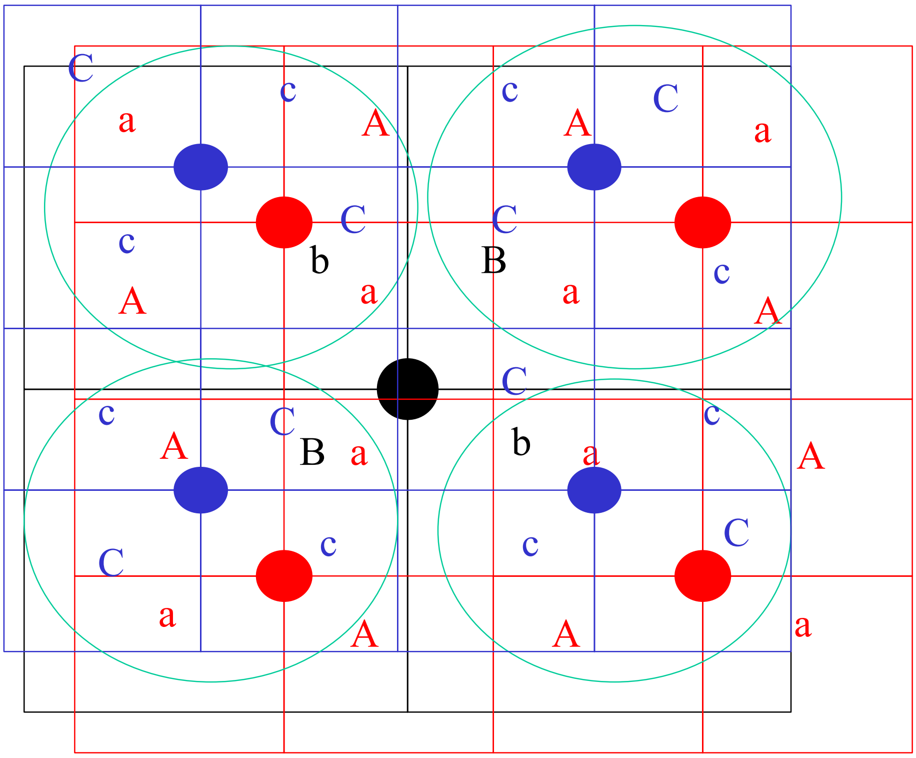



**Figure 1c**